

THREE ESSAYS ON ECONOMIC GROWTH AND TRADE
CONSIDERING ENERGY AND ENVIRONMENT

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PREFACE

Background and Focus

As the assessment reports of the Intergovernmental Panel on Climate Change (IPCC) editorialize, the tocsin posed by it becomes harsh. This means that the earth is more and more polluted and the pollution causes physical damage to our life. As the most recent report from IPCC working group 1 acutely pointed out, it is unequivocal that the climate system is warming and the relationship between the human induced contribution to the warming and the observed warming since the mid 20th century is highly causal link (IPCC WG1 AR5, 2014). The majority of the contribution is a combustion from fossil fuel, for example coal, crude oil, and natural gas, since the industrial revolution which began in the 18th century.

Figure 1 expresses the relation of the temperature, CO₂ emissions, and damage from natural disasters in the world from 1959 to 2010. At first, the upper right of the figure shows that a relation between an atmospheric CO₂ and a temperature in a global land and ocean. This is a climatological relation and shows that an increasing a positive radiative forcing brings about an increase in temperature. The bottom right of the figure shows the relation between an atmospheric CO₂ and CO₂ emissions from fossil fuel combustion and cement production. The emissions derive from human activity and the activity increases global temperatures through an increase in the atmospheric CO₂. On the other hand, the upper left of the figure expresses the relation between the global temperature and damages from natural disasters. The whole figure indicates a possibility that the human activity causes an increase in the damage through climate change. This observed fact strongly supports a mitigation to reduce a consumption of fossil fuel or enhance sinks of greenhouse gases.

However, the mitigation is a challenge facing humanity; a reduction of use of fossil fuel and economic growth is the trade-off. The reason is that fossil fuel is an essential good for household consumptions and production operation and a life of abundance is based on fossil fuel since the revolution. To add to the challenge, the trade-off that occurs among different generations makes matters more difficult. It would have to be said that to address climate change has a full agenda although many NGOs, policymakers, and scientists have canvassed their pieces from their perspective over decades. It is also true that some nations have taken a unilateral action to reduce energy use and greenhouse gas emissions in the relatively recent years in this adverse situation. Although it seems that a high crude oil price is a crucial contribution to these nation actions, it is expected that this action is expanded to the framework of an international cooperation.

It is found that the mitigation policy to be adopted by major countries holds an integrated multiple policy objectives. AR 5 of WG 3 points out that the literatures to focus on the policy designed to the objectives has increased since the AR 4. Such a representative integrated multiple policy objectives is the climate and energy package in European Union, and they are a combination of three major objectives: A 20 percent reduction of greenhouse gas emissions, 20 percent energy production from renewable energy, and 20 percent improvement of energy efficiency in EU. It seems that an integrated multiple policy objectives is the effective way to accomplish the ultimate policy target

where each policy objective ends up, as the case now stands, to mitigate a climate change. One of main focuses in the dissertation is the effect of the integration on the economic growth, in particular, to consider the economy to use both fossil fuel and renewable energy as a factor of production.

When major countries consider and implement the climate change policy to have an integrated multiple policy objectives since AR 4¹, they start considering the policy options that is different from the previous case to promote an international harmonization to mitigate a climate change. These options are a penalty to impose on the countries with lower environmental standard than them or without implementation of the policy. This differs from the Kyoto protocol in that the protocol brings all nations in a common framework to mitigate climate change. In this situation, it is significant to look into the effect of only one country's mitigation policy without any progress of globally harmonized mitigation policy on the domestic market. This is the second focus in the dissertation.

It is thought that a lack of global harmonized mitigation policy leads to the carbon leakage. The leakage is a relocation of installations in industry to the other countries with a laxer energy or CO₂ regulation. This has been discussed as so-called pollution haven in the context of environmental economics. The pollution haven hypothesis is theoretically discussed but it is hard to observe the issue empirically over the past few decades. It is true that different level of the stringency of the regulation changes allocation of resources among the industries in the global economy; the difference distorts a comparative advantage in the international trade. On the other hand, it is pointed out that technological innovation with respect to energy use and pollution abatement is accelerated due to stringent environmental regulation. Considering the implementation of mitigation policy in the countries, as mentioned above, it is important to investigate the impact of recent regulation on the international trade through the comparative cost induced by technology change. This is the final focus in the dissertation.

The Organization of Dissertation

This dissertation consists of three essays on the economic growth under energy resource constraint and trade considering environmental regulation. The chapter 1 analyzes the taxes levied on the nonrenewable energy sector and the subsidies awarded for renewable energy use. Applying the decentralized economy model with a parallel use of two types of energy, it is find that the decentralized economy cannot attain the social optimum due to externality in the market economy. Using optimal tax to attain the social optimum in the decentralized economy entails imposing it on the nonrenewable energy sector. Using damage functions for simulation in the model, it is found that the worse the environmental damage is, the larger the cost.

¹ AR 4 WG 3 described that 67percent of global GHG emissions in 2012 were subject to national legislation or strategies, and it increased that 45percent in 2007.

The chapter 2 analyzes the impact of climate policy on industries in major developing and developed countries. When one country considers implementing a policy, it is important to understand its anticipated effect in the context that other major countries have also implemented policies to reduce fossil fuel consumption. It is analyzed this impact using industry level data for forty countries. Our results show that several industries and countries experience competitiveness effects, and most impacts are not large. It is suggested that the protection of particular industries is less effective within a global agreement, however a global agreement is a more efficient way for more competitive effective countries to limit negative influence on their economy.

The chapter 3 analyzes the effect of comparative advantage in terms of environment-related efficiency on export performance. The implication from the recent theoretical model in international trade suggests that the comparative advantage in an energy-related productivity lead to the export performance through inducement of comparative advantage. This empirical analysis finds that the environment-related efficiency measured by energy use and pollution emissions as unit of production positively affect the export performance of an industry. The empirical results further show that the impact of the efficiency depends on industrial characteristics. In particular, the efficiency has smaller impact on export performance in relatively less footloose industries.

Figure

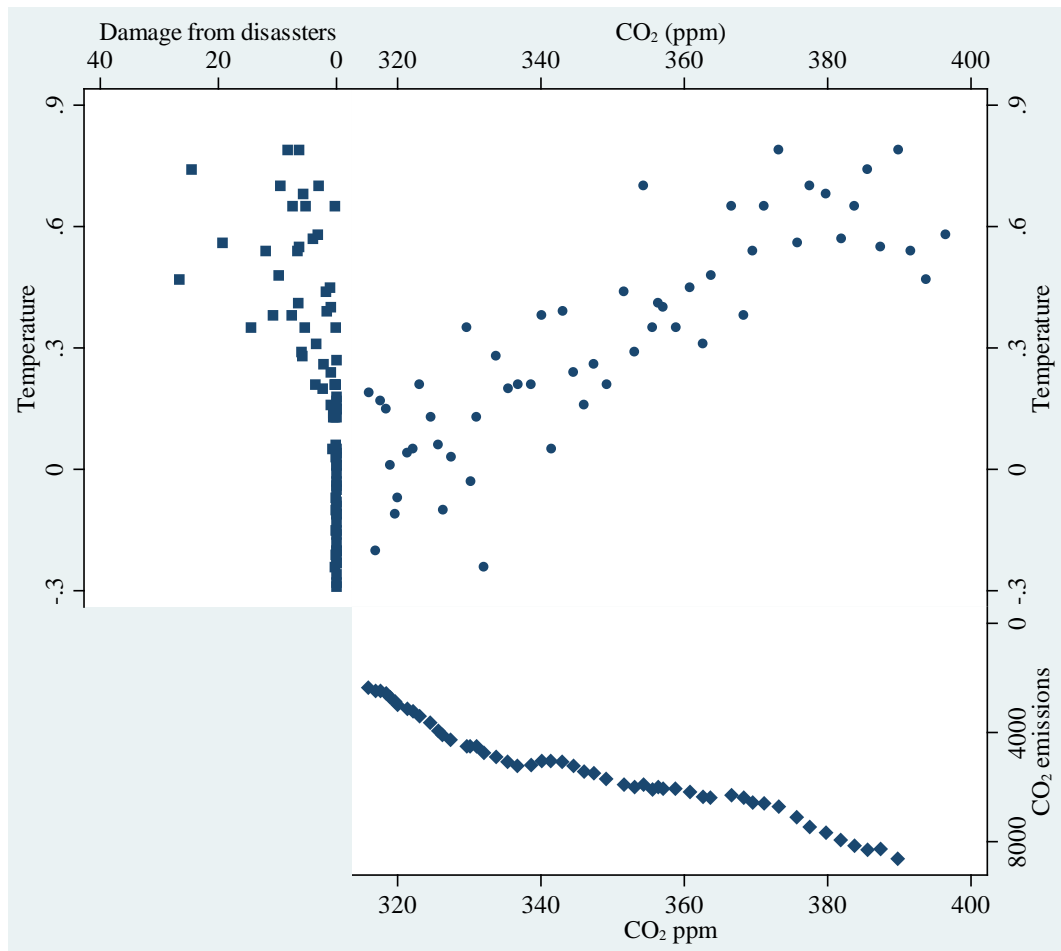


Figure 1 World CO₂ emissions, temperature, and damage from natural disasters

Note: CO₂ emissions is the total emissions from fossil fuels and cement production, and million metric tons of carbon from the carbon dioxide information analysis center in the U.S. CO₂ ppm is an atmospheric CO₂ from the earth system research laboratory in the U.S. Temperature is a global land and ocean temperature anomalies and degrees celsius from the national climatic data center in the U.S. The damage is damages from natural disasters in the world and million U.S. dollars from the international disaster database.

Chapter 1 OPTIMAL ECONOMIC GROWTH AND ENERGY POLICY: ANALYSIS OF
NONRENEWABLE AND RENEWABLE ENERGY

1 Introduction

A trade-off exists between addressing climate change and economic growth. Fossil fuel fueled economic growth during the industrial revolution, and it will remain a key energy source in the future (IEA, 2013). However, rising greenhouse gas concentrations are likely the reason behind the increase in temperatures over the last 50 years (IPCC, 2013), and almost all greenhouse gas emissions are CO₂ from fossil fuel combustion. Such an antinomic relationship produces anxiety in policy makers about how to ensure economic growth while combatting climate change. Therefore, it is essential that policy makers develop measures to attain economic growth while mitigating climate change.

Several nations have attempted to implement a policy mix of decreasing fossil fuel consumption while increasing renewable energy. The European Union enforced one example of this policy mix in the legislation for its climate energy package. Promoting renewable energy can spur economic growth and provide mitigation, by, for example, offering financial support. Climate policies can increase economic output both directly and indirectly (Hallegatte et al., 2012). Considering the environment to be productive capital, an increase in environmental input through environmental policy leads to economic output. Previously, researchers have noted that correcting market failures resulting from policy indirectly increase economic output¹.

By promoting renewable energy as a mitigation policy, furtherance is an effective mitigation policy, at least in the short run. This short-run success occurs because renewable energy technology is already available and is economically efficient compared to other zero emissions energy or technologies (see IPCC, 2011). In addition, enforcing incentive-based policies contributes to the promotion of renewable energy as well as to the abatement of CO₂ emissions. This policy includes a tax on fossil fuel and the auction of emissions allowances. This is a typical mitigation policy that involves a policy mix. This type of policy raises the revenue needed to support the usage of renewable energy.

Previous studies have addressed economic growth in the context of environmental and resource economics. These studies are broadly classified into two categories: one category investigates an exhaustible energy resource stock where the stock decreases as fossil fuel is consumed (e.g., Hotelling, 1931, Barrett, 1992), and the other category captures the dynamics of a pollution stock where the stocks increase as pollutants are used (e.g., Gradus and Smulders, 1993, Stokey, 1998). In particular, Tahvonen and Kuuluvainen (1993) analyzed economic growth using stock pollution and renewable resources, the latter of which are described as a smooth substitution for emissions.

Previous studies have largely failed to analyze climate policy by considering the relationship between economic growth and the implementation of a policy mix. This is because most studies

¹ Hallegatte et al. (2012) highlighted the four channels through which environmental policies can theoretically increase economic output: input effect, efficiency effect, stimulus effect, and innovation effect. The policy mix is closely related to these channels, and we pay special attention to the input effect. That is, we analyze the relationship between economic growth and the shift of energy usage to renewable energy from fossil fuel use.

have focused on one type of resource input even though it is crucial to describe the simultaneous use of nonrenewable and renewable energy. Our challenge in this paper is to examine how economic growth is attained under the simultaneous use of two energy inputs.

The main purpose of our paper is to consider an optimal growth model with a stock of nonrenewable energy using a decentralized and competitive framework. In particular, we analyze the substitutable inputs of nonrenewable and renewable energy following Tahvonen and Salo (2001). This model contrasts with other economic growth-resource depletion models in which only one type of energy contributes to production over time, even after considering a backstop technology (see Dasgupta and Heal, 1974). Our model intends to reflect recent trends in which nonrenewable energy consumption decreases with increasing renewable energy in a phased manner.

Several papers study dynamic economic models focusing on policy instruments, which are closely related to our interest. De Miguel and Manzano (2006) modeled a dynamic stochastic general equilibrium (DSGE) model of a small open economy to import oil and analyzed an oil tax without an exhaustible energy resource stock. The authors found that the distortions of oil prices caused by taxes do not lead to an optimal allocation. Belgodere (2009) considered the optimal climate policy in the presence of oil rents. He showed that a per-unit tax is the policy instrument that obtains the optimal allocation for the provisory decentralized economy model. Fischer and Springborn (2011) analyzed the short-term impact of taxes, emissions caps, and intensity targets on economic growth.

There are only a few studies that assess a policy mix in the context of economic growth. Golosov et al. (2009) analyzed the neoclassical growth model, and Golosov et al. (2014) consequently applied a DSGE model. These works analyzed an externality of the climate change problem using fossil energy as an input to the production function. However, there is only a fossil fuel input for producing the final goods. Acemoglu et al. (2012) analyzed an endogenous and directed technical change in a growth model with environmental constraints, focusing on environmental policy and research subsidies.

Chakravorty et al. (2006) showed that both the low-cost nonrenewable resource and the high-cost renewable resource were used jointly under the binding of the stock of emissions. They showed that supplementing the energy supply through clean renewable resources meets the environmental standard when energy demand declines in the long run. Moreover, energy demand returns to dirty fossil fuels in the future when the ceiling becomes non-binding.

van der Ploeg and Withagen (2012) analyzed optimal climate policy in the presence of exhaustible oil, abundant coal, and CO₂ concentration in the atmosphere. They considered three regimes: only oil use, only coal use, and combining the use of oil and coal. They showed the regime switch of fossil fuel use: the oil-only phase is followed by an oil/coal phase in the social optimum until oil reserves are fully exhausted, at which point the economy switches to coal.

Our paper is more closely related to van der Ploeg and Withagen (2010). They followed Golosov et al. (2014) and developed a Green Ramsey model with different regimes of energy use. Their framework for incubating different regimes is consistent with Tahvonen and Salo (2001).

We consider the decentralized economy adhering fundamentally to Tahvonen and Salo (2001), but

our paper differs from them in that externalities and policy are included in our model. Externalities come from a monopoly of renewable energy production and environmental damage. Many previous studies have analyzed the relationship between environmental policy and an incentive of R&D to reduce environmental pollution. Fischer et al. (2003) studied the effects of economic incentives to reduce emissions considering technological innovation. Moreover, a polluting firm that invests in environmental R&D affects its strategic position as well as slashes its emissions reduction costs (Montero, 2002a, Montero, 2002b). This suggests that there is an interaction between environmental policy and environmental R&D. In our model, renewable energy is the only technology that reduces environmental pollution by indirectly shifting from nonrenewable energy. Additionally, the energy monopoly is introduced as a character of the structure of actual market.

The remainder of the article is organized as follows. Section 2 introduces our analytical framework. Section 3 considers the optimal tax, which can be derived by comparing the decentralized economy problem with the social planner problem. Section 4 provides quantitative examples. Section 5 summarizes the results.

2 The Models

We begin by describing two types of problems to consider the policy mix. One problem is the representative agent problem, and the other is the social planner problem.

2.1 The Social Planner's Problem

2.1.1 The optimal condition

We characterize the socially optimal allocation outcome, that is, the solution to the social planner's problem. Our social planner's problem differs from Tahvonen and Salo (2001) by including environmental damage that depends on a nonrenewable energy stock and an associated policy.

We assume that exhausting nonrenewable energy resources from the ground negatively affects the entire economy. Let $\varphi(X_t)$ denote the damage function, which depends on the stock of nonrenewable energy X_t and satisfies $\varphi(X_t) > 0, \varphi'(X_t) < 0$. A negative impact on the entire economy implies paying for the environmental damage with newly produced value added. This deduction from gross domestic product may be acceptable in light of the amount of damage that has accumulated.

The production function of final goods has Cobb-Douglas technology in respect of capital and energy, and is $AK_t^\alpha(Q_t + S_t)^{1-\alpha}, 0 < \alpha < 1$, where K_t is capital, Q_t is nonrenewable energy use, S_t is renewable energy use and A is a parameter of total factor productivity. We assume that labor employed in the final goods production is a constant, and labor is normalized to one.

Specifying the costs of nonrenewable and renewable energy uses, the assumption of the costs follows Tahvonen and Salo (2001). The unit extraction cost depends on the stock of nonrenewable

energy X_t , and is given as $1/X_t$. Payment to nonrenewable energy is Q_t/X_t . The total cost of renewable energy, unlike the extraction cost, depends on renewable energy use S_t , and is given as S_t^σ . We make assumptions that $S_t^{\sigma-1} > 0$, $\sigma(\sigma-1)S_t^{\sigma-2} > 0$, and the marginal cost of renewable energy at $S_t = 0$ is less than $1/X_0$. Payment to renewable energy is equal to the total renewable cost. Economic resource constraint consists of these energy costs as well as environmental damage $\varphi(X_t)$, consumption, C_t , and depreciation of capital stock, δK_t ; $\dot{K}_t = AK_t^\alpha(Q_t + S_t)^{1-\alpha} - C_t - Q_t/X_t - S_t^\sigma - \delta K_t - \varphi(X_t)$ where δ is a rate of depreciation, and an initial capital stock K_0 is given. We assume that an initial stock of nonrenewable energy X_0 is given. At each period t , the stock decreases according to a law of motion, $\dot{X}_t = -Q_t$.

Finally, we assume that the representative agent has an instantaneous utility function with the constant elasticity of inter-temporal substitution. The social planner maximizes the utility function at period 0 that is discounted by the rate of time preference ρ , subject to the economic resource constraint and the motion of resource depletion. The current value Hamiltonian for this problem is $\mathcal{H}_c = (C_t^{1-\theta} - 1)/(1-\theta) + \lambda_t^K \{AK_t^\alpha(Q_t + S_t)^{1-\alpha} - C_t - Q_t/X_t - S_t^\sigma - \delta K_t - \varphi(X_t)\} - \lambda_t^X Q_t$, where λ_t^K is a co-state variable for capital stock and λ_t^X is a co-state variable for stock of nonrenewable resources.

After eliminating the co-state variables, the first order conditions reduce to the two following conditions:

$$\theta \dot{C}_t / C_t = F_K - \delta - \rho \quad (2.1)$$

$$\frac{\dot{F}_E - (1/X_t)}{F_E - 1/X_t} = F_K - \delta + \frac{-Q_t/X_t^2 + \varphi'(X_t)}{F_E - 1/X_t} \quad (2.2)$$

where F is the production function, F_K is the marginal product of capital, and F_E is marginal product of energy. Equation (2.1) is the Ramsey-Keynes equation. The social planner makes a decision about an inter-temporal distribution of consumption according to (2.1). The condition (2.1) requires balancing the merit to increase production, F_K , with the sum of a time rate of change of marginal utility and the demerit to carry over the current consumption ρ .

Equation (2.2) is the Hotelling rule. $F_E - 1/X_t$ in (2.2) is a marginal rent of nonrenewable energy. Q_t/X_t is a cost of nonrenewable energy, which depends on the stock of nonrenewable energy, and Q_t/X_t^2 is a marginal cost of the stock. Considering environmental damage, an optimal extraction takes into account the social cost of environmental damage. The optimal extraction rule is to balance such a merit, F_K , with the sum of a time rate of change of the marginal rent, the marginal cost of resource nonrenewable energy stock and the marginal damage of environment.

2.1.2 Solution in Steady State

We characterize the optimal solution in the steady state in the social planner problem. A steady state is a situation where growth rates of variables are constant and the rates in the long run are zero due to the assumption that the production function is neoclassical and decreases the marginal product

of capital with an increase in capital. At such a steady state, $\dot{X}_t = Q_t = \lambda_t^X = \lambda_t^K = \dot{K}_t = \lambda_t^K = \dot{C}_t = 0$ ², a relationship between capital stock and nonrenewable energy stock at the steady state is described as $\bar{X} = \bar{K}^{\frac{\alpha(1-\sigma)}{\sigma+\alpha-1}} / (\sigma\omega_1^{1-\omega_2\alpha})$ using the conditions (A.2) and (A.3). Because a differentiation of this equation, $d\bar{X}/d\bar{K}$, is negative in the assumption of parameters³, it is found that the optimal nonrenewable energy stock is a decreasing function of capital stock. The economy that consumes more nonrenewable energy leads to low nonrenewable energy stock and high capital stock at steady state because more nonrenewable energy and less capital stock are made available for final goods production.

The marginal cost of nonrenewable and renewable resources is to obey $1/\bar{X}$ and $\sigma\bar{S}^{\sigma-1}$, respectively, and the prices of both types of energy are equivalent at equilibrium. When renewable resource elasticity of the total cost σ increases, the energy price at the steady state is higher and creates an incentive to produce more nonrenewable energy. In this model, large σ leads to an increase in energy prices and a decrease in the stock of nonrenewable energy. Additionally, capital stock remains higher due to the relationship between \bar{X} and \bar{K} .

Table 1-1 summarizes the steady state of nonrenewable energy, capital stock, renewable resources, and consumption. From the steady state of three variables, the damage to the economy due to an elimination of nonrenewable energy does not affect \bar{X} , \bar{K} , and \bar{S} .

<Table 1-1>

2.2 The Representative Agent Problem

2.2.1 Behavior of Agents

(i) Final Good Sector

At each time t , the final goods producer is faced with a perfect competitive market and maximizes its own profit. The profit function is $\Pi_t^F = AK_t^\alpha(Q_t + S_t)^{1-\alpha} - (r_t + \delta)K_t - p_t^Q Q_t - p_t^S S_t$ where p_t^Q is the price of nonrenewable energy, p_t^S is price of renewable energy, and the other variables are the same as those in the social planner problem. Three first order conditions with respect to K_t , S_t , and Q_t yield the following equations: $\alpha AK_t^{\alpha-1}(Q_t + S_t)^{1-\alpha} = r_t + \delta = F_K$, $(1 - \alpha)AK_t^\alpha(Q_t + S_t)^{-\alpha} = p_t^S = F_E$, and $p_t^Q = F_E$.

(ii) Renewable Energy Sector

We assume that the producer of renewable energy retains perpetual monopoly rights over

² This is derived from the Hotelling rule, taking into account an extraction cost that depends on nonrenewable energy stock and on the ordinary results of the neoclassical growth model.

³ $d\bar{X}/d\bar{K}$ is equal to $\alpha(1 - \sigma) / \{(\sigma\omega_1^{1-\omega_2\alpha})(\sigma + \alpha - 1)\} \bar{K}^{\{(1-\sigma)(\alpha+1)-\alpha\}\omega_2}$, and negative from assumptions of renewable energy cost and parameters.

production and sale. The producer's revenue is equal to the price $p_t^S(S_t)$ times the amount of renewable energy sold, and the total cost is S_t^σ . The producer has the profit function of $\Pi_t^S = p_t^S S_t - S_t^\sigma$.

Profit maximization for this monopolist becomes a static problem because there are no inter-temporal features in the profit function. The producer maximizes own profit at a single point in time, and the first order condition yields $p_t^S(S_t) = \sigma S_t^{\sigma-1} / (p_t^{S'} \cdot S_t / p_t^S + 1)$, taking derivatives of the profit function with respect to S_t .

From the condition of the final goods sector, p_t^S and $p_t^{S'}$ are obtained as $(1 - \alpha)AK_t^\alpha(Q_t + S_t)^{-\alpha}$ and $-\alpha(1 - \alpha)AK_t^\alpha(Q_t + S_t)^{-\alpha-1}$, respectively. Then, p_t^S and $p_t^{S'}$ are plugged into the first order condition, obtaining $p_t^S(S_t) = \sigma S_t^{\sigma-1} / (1 - \alpha S_t / (Q_t + S_t))$. Additionally, $-\alpha S_t / (Q_t + S_t)$ is the markup on the marginal cost of renewable energy production.

(iii) Nonrenewable Energy Resource Sector

We assume that the nonrenewable energy resource producer maximizes own profit on the competitive market at each time t . The profit function is $\pi_t^Q = p_t^Q Q_t - Q_t / X_t$. The producer maximizes own discounted profit function $\int_t^\infty \pi_t^Q \exp(\int_t^s r(u)du)ds$, subject to the constraint of nonrenewable energy stock. This maximization yields the equilibrium $\frac{p_t^Q - 1/X_t}{p_t^Q - 1/X_t} = r_t - \frac{Q_t/X_t^2}{p_t^Q - 1/X_t}$, and TVC is $\lim_{t \rightarrow \infty} \mu_t^X X_t = 0$, where μ_t^X is the present value co-state variable of X_t . $P_t^Q - 1/X_t$ is a marginal rent of nonrenewable energy, and (2-3) implies that a growth rate of the rent does not exceed an interest rate. This conclusion is derived from the Hotelling rule with the extraction cost depending on the stock of nonrenewable energy. The stock at steady state remains finite in this case. The reason for this is that a certain amount of the stock is required to dig an oilfield. Thus, μ_t^X of TVC is equal to zero.

(iv) Consumer

The representative consumer maximizes own utility function $\int_{t=0}^\infty (C_t^{1-\theta} - 1)/(1 - \theta) e^{-\rho t} dt$, subject to own budget constraint $\dot{M} = r_t M_t - C_t + \Pi_t^E$, where M_t is the consumer's assets and Π_t^E is profits from energy firms. The current Hamiltonian value for this consumer problem is $\mathcal{H}_c = (C_t^{1-\theta} - 1)/(1 - \theta) + \mu_t^M \{r_t M_t - C_t + \Pi_t^E\}$. Differentiating the current value Hamiltonian with respect to C_t yields the Ramsey Keynes condition $\dot{\mu}_t^M / \mu_t^M = \rho - r_t$, where μ_t^M is the co-state variable associated with M_t . TVC is $\lim_{t \rightarrow \infty} e^{-\rho t} \mu_t^M M_t = 0$.

2.2.2 Decentralized Equilibrium and Steady State

Let us denote the equilibrium in the decentralized economy. We assume that the economy is closed so that $K_t = M_t$ and $r = \alpha K_t^{\alpha-1}(Q_t + S_t)^{1-\alpha} - \delta$, and that the demand prices of nonrenewable and renewable energy are equal to the supply prices. The final goods sector demands

the two types of energy toward each energy price, and marginal products of nonrenewable and renewable energy coincide from the optimal condition $F_E = p_t^Q = p_t^S$. In the market equilibrium, we obtain the Keynes-Ramsey rule, which coincides with the condition of the social planner problem (2.1), and the Hotelling rule, which differs from the condition of the social planner problem (2.2). Using the optimal conditions of the final goods sector, renewable energy producer and nonrenewable energy producer, we obtain the Hotelling rule as:

$$\frac{\dot{F}_E - (1/X_t)}{F_E - 1/X_t} = F_K - \delta - \frac{Q_t/X_t^2}{F_E - 1/X_t}. \quad (2.3)$$

Equation (2.3) differs from the Hotelling rule of a social planner problem in two ways: the marginal product of energy contains a markup and there is no marginal damage $\varphi'(X_t)$. The renewable energy sector is assumed exclusively to sell renewable resources, and the markup, $-\alpha S_t/(Q_t + S_t)$, is added over its marginal cost (see 2.2.1(ii)). The markup increases the marginal cost of renewable resources, and the marginal cost of extraction also increases at equilibrium. The price of nonrenewable energy leads to more extraction of nonrenewable energy and exacerbates the environment.

We consider the optimal solution in the steady state. The markup at the steady state is equal to $1/(1 - \alpha)$ and leads to fewer solutions compared with the social planner. The relationship between both stock of capital and nonrenewable energy at the steady state is derived from the optimal condition of the final goods sector and becomes $\bar{X} = \bar{K}^{\frac{\alpha(1-\sigma)}{\sigma+\alpha-1}} / (\sigma m^{\alpha\omega_2} \omega_1^{1-\omega_2\alpha})$, where m is the markup. Figure 1-1 indicates the relationship of optimal capital and nonrenewable energy stock at steady state. Both curves of the social planner and market economy are downward-sloping⁴. The steady state solution of the market economy is decreased by the markup compared to the solution of the social planner. The effect of the markup in the renewable resources sector represents the shift of the capital and nonrenewable energy curves in Figure 1-1. The effects of markups on capital, nonrenewable energy stock and renewable resources is $(1 - \alpha)^{2\alpha\omega_2}$, $(1 - \alpha)^{(1-\alpha)\omega_2}$ and $(1 - \alpha)^{(\sigma-\alpha-1)\omega_2/(\sigma-1)}$, respectively. Form our assumption of parameters, markups lead to lower solutions relative to the social planner solutions. Capital stock, nonrenewable energy stock, and renewable energy at steady state are summarized in Table 1-2.

<Table 1-2>

<Figure 1-1>

3 Optimal Policy

In this section, we analyze the optimal policy. We show the optimal tax, making an exposition of the discrepancy between the representative agent's problem and the social planner's problem.

⁴ $d\bar{X}/d\bar{K}$ is negative in the cases of the social planner and the market economy.

3.1 Energy Policy Considering the Environment

There are externalities in the decentralized economy in the previous section, and we consider how to address them. The social planner can attain the optimal allocation. However, the market economy creates inefficiency, which is due to externalities.

We introduce the government, which makes the market economy efficient, and assume that the government realizes the optimum social outcome using a policy measure. Such a policy entails removing supply shortages of renewable energy by monopolists and adding to the social cost of the environmental damage. We consider the tax and subsidy as the policy and assume that the government may finance a source of the subsidy with tax revenues.

As in Xepapadeas (2005), we assume that tax to create the optimal conditions associated with a market economy in line with that of the social planner. In the two cases, such a different optimal condition is related to the Hotelling rule. The rule of the market economy is derived from the behaviors of final goods producers and nonrenewable energy producers. From the optimal conditions of the final goods sector (see 2.2.1(i)), it is apparent that the tax on the nonrenewable energy use of the final goods producer cannot achieve an alignment of the optimal conditions of the social planner and the market economy.

We focus on the tax levied on the nonrenewable energy sector, and introduce a profit tax τ_t . The profit tax is imposed on a profit of nonrenewable energy extraction at time t , and the profit function of the sector is altered to $\tilde{\pi}_t^Q = \pi_t^Q(1 - \tau_t)$. The Hotelling rule in this case is obtained as follows:

$$(\dot{p}_t^Q - 1/X_t)/(p_t^Q - 1/X_t) = F_K - \delta - \frac{Q_t/X_t^2}{p_t^Q - 1/X_t} + \dot{\tau}_t/(1 - \tau_t) \quad (3.1)$$

where r_t is an interest rate. Compared to (2.2) and (3.1), the profit tax term of (3.1) corresponds to the marginal damage term of (2.2). Implementing the social planner solution using the profit tax in the market economy, the time variation of profit tax is equal to the ratio of the marginal environmental damage to the net royalty from the sale of nonrenewable energy, which means $\dot{\tau}_t = \varphi'(X_t)(1 - \tau_t)/(F_E - 1/X_t)$.

Another policy for implementing the social planner solution in the market economy is likewise considered to match both optimal conditions of the social planner and the market economy. Such a condition is obtained from the optimal condition of renewable sector and (A.2). The renewable sector in the market economy is assumed to be a monopolist supply, which raises less production compared to perfect competition. The renewable resource price exceeds a marginal cost of the renewable resource by the rate of a reciprocal of the price elasticity of demand in the monopoly market. In this case, the subsidy is introduced to support the excess and is denoted by $i_t^S = \alpha S_t/(Q_t + S_t)$.

The government's budget constraint becomes balanced at each period. Thus, the budget constraint yields $\pi_t^Q \tau_t^X + T_t = i_t^S p_t^S$, where T_t is a lump-sum tax on the household. The lump-sum tax plays a role as adjustment for the balance of tax revenue and subsidy expenditure, and does not change the

optimal condition of the consumer.

3.2 Optimal Tax

Energy policy addresses two types of externalities, monopoly and environmental damage, and attains the social optimum when the government introduces taxes and subsidies. We focus on such an optimal policy in this section and assume that distortions in the market are clear, which means that the tax and subsidy policy is optimally implemented.

The optimal tax is obtained from (3.1) as the time differentiation $\dot{\tau}_t = (1 - \tau)\varphi'(X_t)/(p_t^Q - 1/X_t)$. An interesting policy issue is whether the profit tax rate is rising or falling. To determine this, we consider the solution of a differential equation of the profit tax rate. We let $v = (1 - \tau)$, which means a profit ratio of the nonrenewable energy sector, and $\dot{\tau} = -\dot{v}$. Substitute τ and $\dot{\tau}$ into the differential equation of the profit tax and we obtain a profit ratio equation $\dot{v}_t = e^{-\int_0^t m_s ds} v_0$, where v_0 is a constant of integration and an initial value of v , and m_s is $\varphi'(X_t)/(p_t^Q - 1/X_t)$. From the definition of v , the profit tax rate is obtained as $\tau_t = 1 - e^{-\int_0^t m_s ds} v_0$.

The profit tax rate decreases as time goes on. v_0 is a profit ratio at an initial period and satisfies $0 \leq v_0 \leq 1$. m_t is negative at each time $t \in [0, +\infty)$ because $\varphi'(X_t)$ is assumed to be negative and $p_t^Q - 1/X_t$, which is the rent of the nonrenewable energy producer and is typically positive. From these equations, the profit rate of the nonrenewable energy sector increases, but optimal tax τ_t decreases.

4 Simple Quantitative Considerations

In this section, we show the results of a simple quantitative analysis. We clarify the dynamic path of key variables. We focus on the profit tax on the nonrenewable energy resource sector as policy for the environment. Additionally, the subsidy to the renewable resource sector is implemented in the following simulation.

4.1 Parameter Choices

We analyze the impact of the optimal tax on the path of the key variables. When the optimal tax on the profits of the nonrenewable energy sector is imposed and the budget of the government is balanced, a solution of the decentralized economy is consistent with one of the social planner problems. In this context, we investigate a comparison between tax and no tax.

The common parameters are listed in

Table 1-3. Most of the parameters are from Tahvonen and Salo (2001). In addition, we specify an environmental damage loss function of nonrenewable energy stock. See the specification of this function in the following subsection (see 4.2).

<Table 1-3>

4.2 Environmental Damage Loss

The economic model involves the atmosphere systems from Nordhaus's DICE model. He adopts the damage function from a global temperature. The temperature is described on an elaborate atmosphere system and the law of motion for a carbon concentration in the atmosphere. Golosov et al. (2009) considered the negative impact of environmental damage on total output, and the damage loss increases as the nonrenewable energy stock decreases.

The damage function in line with our model is a direct relationship between damage loss and nonrenewable energy stock. We assume that a damage loss function is a log linear relationship in a nonrenewable energy stock $\Phi(X_t) = b - a \log(X_t)$. The supposition describes an expansion of environmental damage with a decrease in the stock. Moreover, a log linear relationship is made available so that damage loss at the initial term is normalized to zero.

Figure 1-2 represents the CO₂ emissions from fuel combustion and nonrenewable energy stock, measured as CO₂. The stock in 1998 decreases as the law of motion for the stock⁵, which is $X_{t+1|CO_2} - X_{t|CO_2} = -Q_{t|CO_2}$, where $X_{t|CO_2}$ is a stock of a nonrenewable resource and $Q_{t|CO_2}$ is a flow of the energy measured as CO₂. The emissions in 2050 are derived from Stern (2007) and are estimated to be 61 Gt-CO₂. It is assumed that this estimation will increase linearly until 2050.

<Figure 1-2>

We obtain damage loss functions from the nonrenewable energy stock and damage loss up to 2050. Future damage is derived from the results of the Stern review, where 5 percent of global GDP is lost each year without climate action. Hence we set two cases: damage loss at 5 percent of annual global GDP and damage loss at 1 percent of annual whole GDP. We estimate the function using calculated GDP loss. The functions are as follows:

$$[1 \% \text{ of GDP loss}] \quad \Phi_t = -0.015 \log(X_t) - 0.148 \quad (3.2)$$

$$[5 \% \text{ of GDP loss}] \quad \Phi_t = -0.041 \log(X_t) - 0.04 \quad (3.3)$$

These functions were obtained by adjusting from the original figures in our model. Figure 1-3 describes upper and lower damage loss functions of 5 percent loss and 1 percent loss, respectively.

<Figure 1-3>

4.3 Simulation Results and Imprecation

4.3.1 Results

We illustrate the simulation results using the calculated damage loss functions in 4.2. We set three cases in our simulation: market economy, 1 percent loss, and 5 percent loss. Although there is no consideration in the market economy case of the environmental impact of consuming nonrenewable energy, the 1 percent loss case and 5 percent loss case introduce the profit tax on the

⁵ The stock in 1998 is estimated by the World Energy Council (2000) to be 24,061 Gt-CO₂.

nonrenewable energy sector. We assume that the government is concerned with future environmental damage loss. When the government's perspective on damage loss is serious, the damage loss function provides higher damage losses. In our model, the higher the damage loss function is, the more rigorous the tax. The term of our simulation is 40 periods (from 2010 up to 2050).

We develop the decentralized economy model of the Tahvonen and Salo (2001) in order to consider the externalities and policy. The difference between their model and our model is whether to consider the markets, which are product market, exhaustible energy market, and renewable market. This difference enables us to show the extent of the impact of an improvement in the externality on economy. Our simulation results show that the impact in the 1 percent case remains very small but 5 percent case has the relatively large impact on economy (see the left panel in Figure 1-6). The tax may cause considerable delays of the recovery in consumption under the 5 percent case.

The left panel in Figure 1-4 represents nonrenewable energy use and the right panel represents renewable resource use. The market economy case shows the highest nonrenewable energy use because no tax is imposed. Nonrenewable energy uses in all three cases decrease over time, but there are no wide gaps among them. Similarly, renewable resource uses in three cases are not found to have a wide gap. Renewable resource use in the 5 percent loss case is the highest in the three cases. This is because the profit tax on the nonrenewable energy sector increases the cost of renewable resources and the relative price of renewable resources decreases at the initial period. However, in the aftermath, renewable resource use in the market economy is only slightly higher than in the others cases. Nonrenewable energy use in the market economy case is larger than in the others cases and the speed of depletion is the fastest among the three cases. The most rapid resource scarcity leads to a greater increase in the marginal cost of nonrenewable energy, and an increase in energy prices at equilibrium allows renewable resource use to be extended.

The left panel in Figure 1-5 depicts capital stock, and the right panel depicts nonrenewable energy stock. The capital stock in the 5 percent loss case is the lowest of the three cases. An increase in nonrenewable energy prices leads to a shift from energy use to capital stock in the final goods sector. The nonrenewable energy stock in the 5 percent loss case is the highest of the cases. The 5 percent loss case and 1 percent loss case take into account that the tax policy is geared toward conserving nonrenewable energy and that the stock of the two cases is higher than the stock in market economy case.

The right panel in Figure 1-6 shows consumption and the left panel shows production. Production decreases over time in both cases. Production in the market economy case is the highest over time among the three cases. Productions decrease from the initial period to approximately the fifth period and increase after that. A decrease of the productions is derived from a late development capital stock and renewable resource use as substitution of nonrenewable energy use. Consumption in the market economy case is the highest among the three cases. In the model, the rent of the nonrenewable energy sector is received by the household. Therefore, the optimal tax leads to a decrease in consumption.

The introduction of the tax on the nonrenewable energy sector leads to the reduction of nonrenewable energy use and an acceleration of renewable energy use, but the acceleration is not enough to keep the pre-tax level of production (see the left panel in Figure 1-6), because the marginal cost of renewable energy is high as renewable energy use increases (see 2.1.1). It can be observed that the high cost of renewable energy prohibits the progress of the renewable energy use in the actual energy markets.

The capital stock which is another substitutable producer good for nonrenewable energy increases despite the relatively high discount rate in our simulation. One possible explanation for why the capital stock increases has a consumer sentiment to hope saving relative to current consuming throughout the decrease of nonrenewable energy use according to the Hotelling rule (see the equation 2.2). The stock of capital and acknowledge related to renewable energy tends to increase in the world, and a reduction of nonrenewable energy use is an effective way to accumulate the stock further.

Table 1-4 summarizes the damage loss in the market economy case. The stock of nonrenewable energy leads to 21T-CO₂ at the 40th period. When the damage loss in the future follows (3.2), the loss is estimated at approximately \$1,797 billion. The loss of (3.3) is estimated at \$5,614 billion.

<Figure 1-4>

<Figure 1-5>

<Figure 1-6>

<Table 1-4>

4.4 Policy Imprecation

Renewable energy and capital stock are substitutable producer goods in our model, and the substitution accelerates by means of the tax on nonrenewable energy sector. Our simulation shows the new paths of the steady states which are created by the tax. This substitution depicts the penetration of the renewable energy technology in the real economy. The cost function of renewable energy under the assumption can be regarded as the cost curve to arrange the price of the renewable energy technologies in descending order (see 2.1.1). The penetration of renewable energy needs not only the decrease in its own cost but also the adequate price level of nonrenewable energy in order to remain that renewable energy can be contestable in the energy markets. If an excessive price reduction of nonrenewable energy disturbs the penetration of renewable energy in the energy market, the tax to keep the adequate nonrenewable energy price is supportive from a standpoint of the effective penetration.

In addition, it is important to attain the economic growth under the environmental regulations. Our simulation results show the growth after the introduction of the tax (see Figure 1-6), but it is found that consumption recovers to the pre-tax level in slow motion. If the recovery of economy is very low-speed and the slowness conducive to the large damage of the economy, it is also necessary that

the government implement the subsidy policy to recover consumption fast as well as the environmental regulation, because the social welfare enhancing comes from the greener environment with lower economic damage.

5 Concluding Remarks

A current major policy combines a climate policy and a renewable energy policy. We study this policy by applying the optimal growth model to an environmental externality and a monopoly of renewable energy production. We show that levying a tax on the nonrenewable energy resources sector and awarding a subsidy for renewable energy use achieves the social optimum.

Our findings are as follows. A decentralized economy cannot attain the social optimum. Comparing the optimal conditions of the decentralized economy to the social planner's problem, we find that imposing an optimal tax on a nonrenewable energy producer coincides with both conditions. A lump sum transfer of the tax to a renewable energy use causes renewable energy to increase more than in the case without the tax. However, our simulation shows an inversion of magnitudes between the cases with and without taxes on renewable energy. This is because higher energy prices resulting from the scarcity of nonrenewable energy promotes the use of renewable energy.

Other simulation results show the social losses under the damage functions. In our model, a social expense depends on the magnitude of social damage to the environment. A social loss in the 1 percent loss case costs \$1.8 trillion, and a social loss in the 5 percent loss case costs \$5.6 trillion. We show that consumption and production are the lowest in the 5 percent loss case. This case has the highest amount of social damage.

In particular, we consider the monopoly of renewable energy production. This is one of the externalities in our model. The monopoly causes less supply of renewable energy, and constitutes barriers to the mitigation of climate change and to economic growth. We do not sufficiently examine the renewable energy market, but it is possible for the high-tech and major-scale renewable energy source industry to have a large fixed cost.

Our paper demonstrates a policy assessment using two types of energy. Several directions appear fruitful for future research. First, developing our model and an endogenous economic growth model would be useful because the economy is growing under a nonrenewable energy constraint. Second, pollution from the combustion of nonrenewable energy can be taken into account. The externality of pollution is different over nonrenewable energy. Thus, the results of this paper may provide different implications. Finally, we implicitly assume a closed economy. It is important to consider a global economy with a tax and a climate fund.

APPENDIX

A.1 Social Planner Problem

The necessary conditions for the social planner problem in section 2.1 are:

$$[C_t]: \quad C_t^{-\theta} - \lambda_t^K = 0 \quad (\text{A.1})$$

$$[S_t]: \quad (1 - \alpha)Y_t/E_t - \sigma S_t^{\sigma-1} = 0 \quad (\text{A.2})$$

$$[Q]: \quad \lambda_t^K \{(1 - \alpha)Y_t/E_t - 1/X_t\} - \lambda_t^X = 0 \quad (\text{A.3})$$

$$[K_t]: \quad \dot{\lambda}_t^K / \lambda_t^K = \rho + \delta - \alpha Y_t/K_t \quad (\text{A.4})$$

$$[X_t]: \quad \dot{\lambda}_t^X / \lambda_t^X = \rho - (\lambda_t^K / \lambda_t^X)(Q_t/X_t^2 - \varphi'(X_t)) \quad (\text{A.5})$$

$$[TVC]: \quad \lim_{t \rightarrow \infty} e^{-\rho t} \lambda_t^K K_t = 0, \quad \lim_{t \rightarrow \infty} e^{-\rho t} \lambda_t^X X_t = 0. \quad (\text{A.6})$$

The expression for differentiating (A.1) with respect to time is plugged into (A.4). The Ramsey-Keynes conditions (2-1) are thus obtained.

Plugging (A.4) and (A.5) into the expression to differentiate (A.3) with respect to time, we have

$$\frac{\dot{F}_{E,t} - (1/X_t)}{F_{E,t} - 1/X_t} = F_{K,t} - \delta + (Q_t/X_t^2 - \varphi'(X_t))(\lambda_t^K / \lambda_t^X),$$

where F_E is a marginal product of renewable resources and F_K is a marginal product of capital. Using $\lambda_t^K / \lambda_t^X$ from (A.3), the Hotelling rule (2.2) is obtained.

We look at the steady state with the social planner problem where the variables $\dot{X}_t, Q_t, \dot{\lambda}_t^X, \lambda_t^X, \dot{K}_t, \lambda_t^K$, and \dot{C}_t equal zero. Using the optimal condition (A.2), renewable energy is obtained as $\bar{S} = \left(\frac{(1-\alpha)A_t}{\sigma} \right)^{\frac{1}{\sigma+\alpha-1}} \bar{K}^{\frac{\alpha}{\sigma+\alpha-1}}$, which is expressed as a function of \bar{K} . Moreover, the ration of two co-state variables from (A.3) at steady state is expressed as $(1 - \alpha)A\bar{K}^\alpha \bar{S}^{-\alpha} = 1/\bar{X}$. Plugging \bar{S} into this equation, we obtain the relationship between a capital stock and a nonrenewable resource stock at steady state. The capital stock at steady state is obtained from (A.4), together with \bar{S} .

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TABLES

Table 1-1 Solutions at steady state in the social planner.

Exhaustible resource	Capital stock	Renewable resource
$\frac{\left(\frac{\rho + \delta}{\alpha A \omega_1^{\omega_2(1-\alpha)}}\right)^{\frac{\alpha}{1-\alpha}}}{\sigma \omega_1^{1-\omega_2\alpha}}$	$\left(\frac{\rho + \delta}{\alpha A \omega_1^{\omega_2(1-\alpha)}}\right)^{\frac{\sigma+\alpha-1}{(1-\alpha)(1-\sigma)}}$	$\omega_1^{\omega_2} \left(\frac{\rho + \delta}{\alpha A \omega_1^{\omega_2(1-\alpha)}}\right)^{\frac{\alpha}{(1-\alpha)(1-\sigma)}}$

Note: ω_1 and ω_2 are $(1-\alpha)A/\sigma$ and $1/(\sigma+\alpha-1)$, respectively. Optimal output and consumption at steady state are obtained from production function and resource constraint, and optimal nonrenewable energy consumption is zero.

Table 1-2 Solutions at steady state in the decentralized economy.

nonrenewable energy stock	Capital stock	Renewable resource
$(1 - \alpha)^{2\alpha\omega_2} \frac{\left(\frac{\rho + \delta}{\alpha A \omega_1^{\omega_2(1-\alpha)}}\right)^{\frac{\alpha}{1-\alpha}}}{\sigma \omega_1^{1-\omega_2\alpha}}$	$\left(\frac{\rho + \delta}{\alpha A \omega_1^{\omega_2(1-\alpha)}}\right)^{\frac{\sigma+\alpha-1}{(1-\alpha)(1-\sigma)}} (1 - \alpha)^{(1-\alpha)\omega_2}$	$(1 - \alpha)^{\frac{(\sigma-\alpha-1)\omega_2}{\sigma-1}} \omega_1^{\omega_2} \left(\frac{\rho + \delta}{\alpha A \omega_1^{\omega_2(1-\alpha)}}\right)^{\frac{\alpha}{(1-\alpha)(1-\sigma)}}$

Note: ω_1 and ω_2 are the same variables those in Table 1-1.

Table 1-3 Parameter.

Total factor productivity (A)	1	Cost function of renewable energy (σ)	2
Output share of capital (α)	0.06	Depreciation rate (δ)	0.08
Discount rate (ρ)	0.08	Risk aversion coefficient (θ)	1.1

Table 1-4 Damage loss in the market economy.

Nonrenewable energy stock at the 40th term. (Gt-CO ₂)	Social loss (billion 2005 US dollars)	
	1% loss damage	5% loss case
21,982	1,797	5,614

Note: The 1% loss case is used by a damage function (3.2), and the 5% loss case is used by a damage function (3.3).

FIGURES

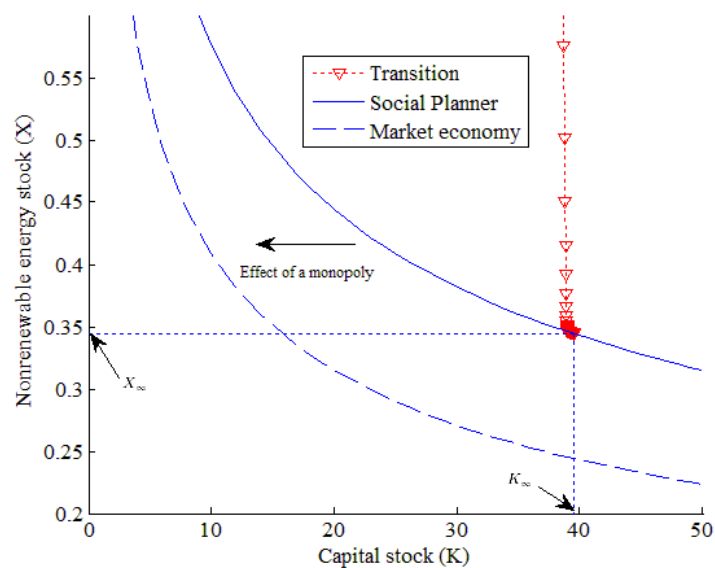


Figure 1-1 Steady state solution of capital stock and nonrenewable energy stock in the social planner and the market economy.

Note: The parameters of these cases in the figure are described in Section 4. The set of values is numerically calculated using our model.

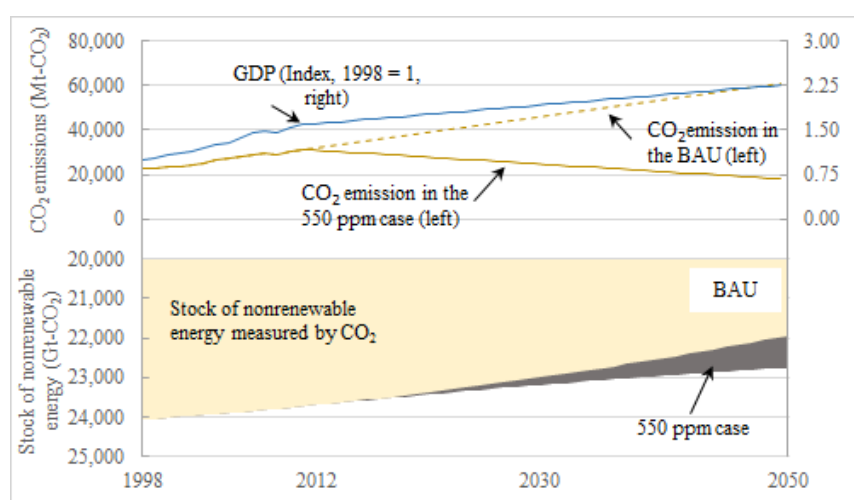


Figure 1-2 Stock of nonrenewable energy and CO₂ emissions from 1998 to 2050.

Note: From World Energy Council (2000), Stern (2007), and IEA CO₂ emissions from fuel combustion.

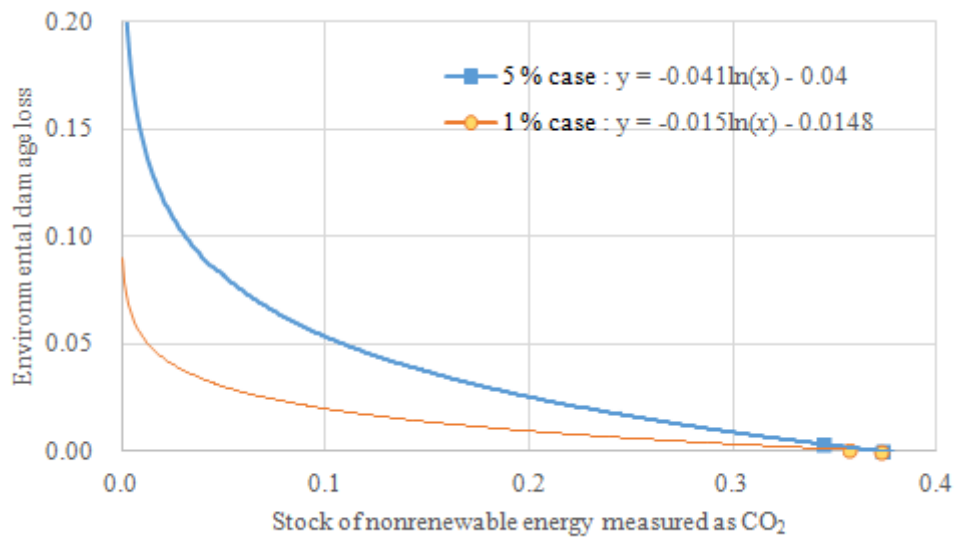


Figure 1-3 Adjusted damage loss function.

Note: Each point is the set of values after we adjust the digit of the original figures in accordance with a digit number of variables in our model, and the unit of the stock is different from the Figure 1-2.

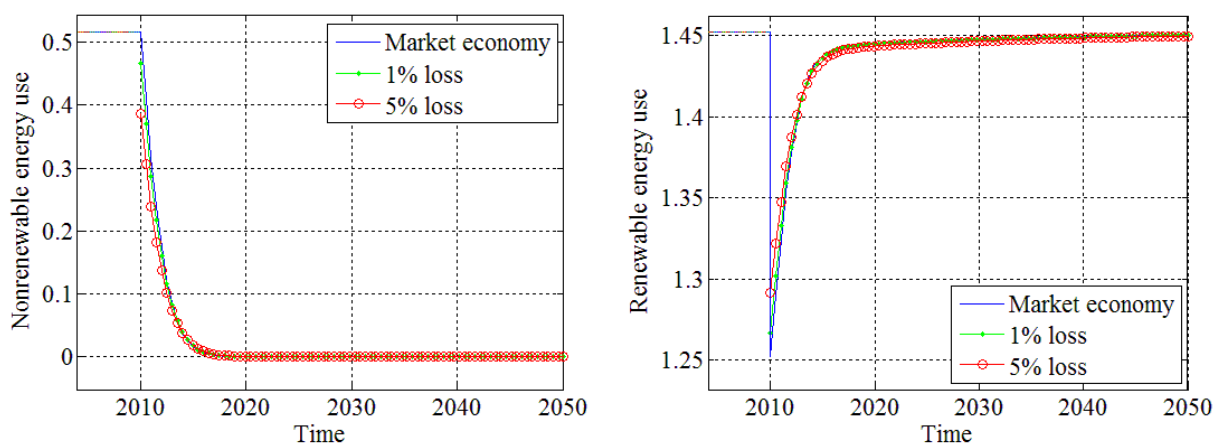


Figure 1-4 Use of nonrenewable energy and renewable energy.

Note: Each point is numerically calculated using our model. The same applies to the following figure 1-5 and 1-6.

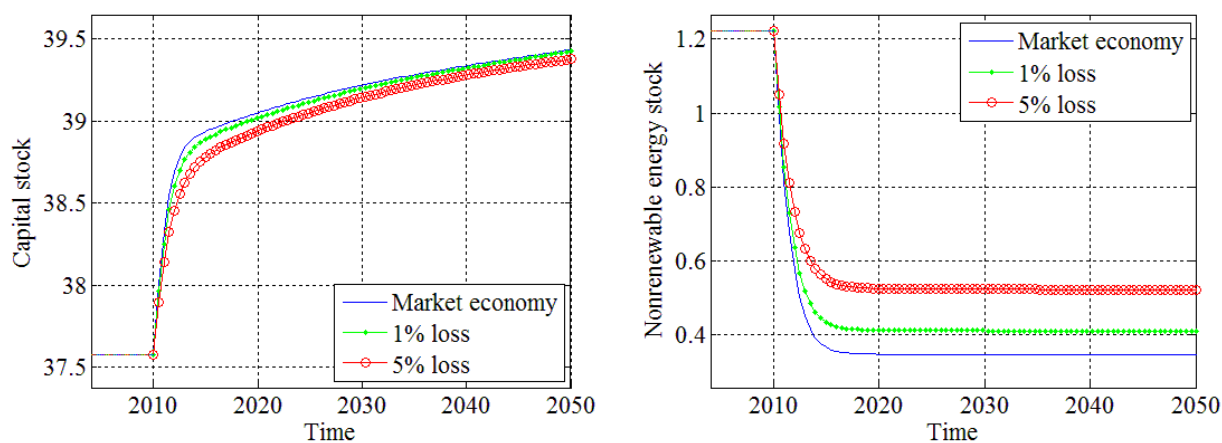


Figure 1-5 Capital stock and nonrenewable energy stock.

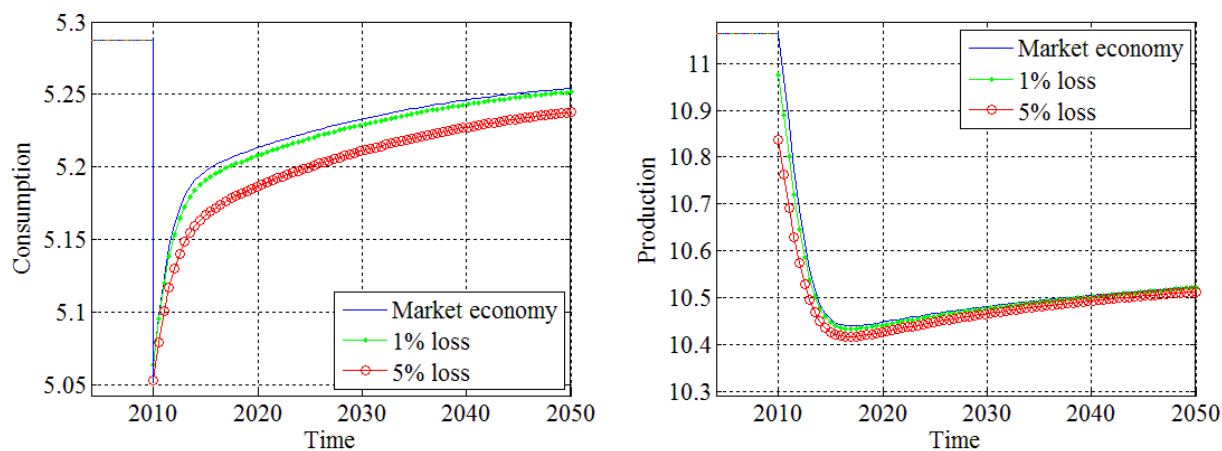


Figure 1-6 Consumption and production.

Chapter 2 ENERGY PRICING IMPACT ON DOMESTIC ECONOMY UNDER RECENT CLIMATE

ACTION

Introduction

It has been hard to reach an international agreement on adequate mitigation goals for an effective global climate policy due to the complex and uncertain nature of the problem; thus, local-level climate policy is becoming increasingly useful (Wang and Chen, 2013). Several nations have implemented domestic mitigation policies that have proven to be effective in significantly reducing emissions (Managi et al., 2009). This paper empirically investigates the effect of domestic and international climate policy on the domestic market in forty countries, under the condition that each country implements its own climate policy.

The circumstances surrounding climate policy have changed in recent years. Several major developed and developing countries have domestically implemented climate and energy policies without waiting for a global climate agreement. Previous research was entirely concerned with the impact of climate policy in one country with a condition that no other countries implement emission reduction policies. However, in reality we need to consider the alternative situation, whereby climate policy is introduced under the condition that other countries have implemented policies as well. This is because there is increased awareness that climate policy has both domestic and global impact.

It is also important to analyze carbon leakage, as the level of regulation varies across countries. In the post-Kyoto, a global agreement will be required to resolve the problem of climate change. However, until such an agreement is delivered, countries are implementing self-imposed climate mitigation regulations. If the world's climate policies remain inharmonious for a long time, it will be important to analyze the impact of a given mitigation policy on both the domestic and global economy. Aldy and Pizer (2011) explored the effect of the United States' (US) emission mitigation policy on the US manufacturing sector using the historical relationship between energy price and production and consumption. This study is a first attempt to focus not only on US manufacturing but also on the impact of other major countries' policies as well, using industry- and country-specific panel data.

In the context of mitigation policy and carbon leakage, recent studies have analyzed border measures. The typical border measure is a tax on importers from a country where a climate policy is not implemented. This penalty on importers is equivalent to the level of regulation that is levied on domestic manufacturers in a country that is subject to a climate policy. Currently, border measures are incorporated in political discussions in the US and the European Union (EU) to obviate the competitive disadvantage of the increase in costs levied on importers¹.

Fischer and Fox (2012) analyzed the effectiveness of a border charge on imports, a border rebate for exports, full border adjustment, and domestic output-based rebating. They show that the

¹ Examples of this are the Waxman – Markey bill (H. R. 2454 “The American Clean Energy and Security Act of 2009”) in the US and the proposal for an EU carbon tariff in France.

impacts of these four border measures depend on the specific sector and country characteristics, including the relative emissions rate, elasticity of substitution, and consumption volumes. Moreover, their simulation results show that a full border adjustment is usually most effective. Dissou and Eyland (2011) analyzed the effects of a border tax adjustment and a combination of a border tax adjustment and sectoral subsidy according to the gross output of domestic producers from the border tax. They illustrate the effect of a border measure using the Canadian economy and show that a border tax adjustment on the importers of non-fossil fuels and energy intensive products leads to a complete reduction of the negative competitiveness impact that domestic producers face from domestic regulation. Ghosh et al. (2012) focused on a border tax only on CO₂ emission or on all greenhouse gases. Using their simulation, their study shows that the policy based on GHG emission has a lower effective cost and leads to less re-distributive effects than the policy based solely on CO₂ emission.

Previous studies using Computational General Equilibrium (CGE) analysis are also relevant to the impact of climate mitigation, as well as border measures (e.g., Fischer and Fox, 2012). Many models of CGE analysis have been developed, but CGE models are made up of a general equilibrium theory and a social account matrix. CGE analysis is well-suited to non-statistical core parameters in a constructed CGE model and is available for analysis when there are insufficient statistical data. Hélène et al. (2012) analyzed the impact of the EU's GHG reduction pledge on additional economic resilience in the increase of oil prices. Their simulation using the GEM-E3, a representative CGE model, shows that EU climate policy leads to economic resilience. Orlov and Grethe (2012) applied CGE analysis to the Russian economy, which is well-blessed with natural resources. They analyzed the effect of a carbon tax on the economy under the assumption of imperfect competition in natural gas, petroleum, and several energy intensive sectors. Wissema and Dellink (2007) analyzed the impact of carbon taxation on related energy usage in Ireland. Their simulation results show that imposing a carbon tax leads to a reduction in energy-related CO₂ emissions.

I follow the methodology developed by Aldy and Pizer (2011), which differs from the previous studies in two aspects. The previous studies consider the impact of domestic climate policy under the assumption that other countries also implement climate policy, as opposed to a border measure. Moreover, while CGE analysis is based on the selection of parameters from the results of various previous studies and calibrations, their analysis is based on statistical estimation. Compared with their analysis, the scope of this analysis was expanded from only the US to include forty countries using the industry level panel data.

The remainder of the article is organized as follows; Section 2 introduces the theoretical framework of competitive effect; Section 3 shows the estimation model used to measure the competitive effect and dataset; Section 4 sums up the results of this estimation; Section 5 considers the competitive effect across the sectors and countries; and finally, Section 6 concludes this analysis.

1 The model

I consider a theoretical framework of implementing domestic regulation in the situation that other countries implement climate policy (see Aldy and Pizer (2011) for detail). Aldy Pizer model the economic impact of regulation on the domestic demand and supply and measure the theoretically derived competitiveness effect. The competitiveness effect is defined as the equilibrium difference of domestic supply change between the presence of domestic and foreign climate policy (S^0) and the presence of only domestic climate policy (S^1). Taking the total derivative of the market equilibrium ($D(p) = S(p, r_H) + NI(p, r_F)$) and supply function ($S(p, r_H)$), we obtain

$$dS_1 - dS_0 = \left(\frac{(\partial S(p, r_H)/\partial p) \cdot (\partial NI(p, r_F)/\partial r_F)}{(\partial D(p)/\partial p - \partial S(p, r_H)/\partial p - \partial NI(p, r_F)/\partial p)} \right) dr_F \quad (2-1)$$

where $NI(\cdot)$ is net import in the presence of only domestic climate policy, $S(\cdot)$ is the domestic supply function, $D(\cdot)$ is the domestic demand function, p is the price of the domestic good, and r_j is regulation in j area (j includes both home (H) and foreign (F)). If the competitiveness effect is empirically analyzed, we are confronted by the difficulty that the data are not available for estimation (2-1). I take the total derivative of the net import function and obtain

$$dNI_1 = \left(\frac{\partial NI(p, r_F)/\partial p}{\partial D(p)/\partial p - \partial S(p, r_H)/\partial p - \partial NI(p, r_F)/\partial p} \right) (\partial S(p, r_H)/\partial r_H) dr_H \quad (2-2)$$

Using equations (2-1) and (2-2), we re-describe the competitiveness effect and change of net import as

$$dS_1 - dS_0 = - \left(\frac{(\partial S(p, r_F))(\partial NI(p, r_F)/\partial p)}{(\partial D(p)/\partial p - \partial S(p, r_F)/\partial p - \partial NI(p, r_F)/\partial p)} \right) \left(\frac{\partial NI(p, r_F)/\partial r_F}{\partial NI(p, r_F)/\partial p} \right) dr_F \quad (2-3)$$

and

$$dNI_1 = \left(\frac{(\partial S(p, r_H)/\partial p)(\partial NI(p, r_H)/\partial p)}{(\partial D(p)/\partial p - \partial S(p, r_H)/\partial p - \partial NI(p, r_H)/\partial p)} \right) \left(\frac{\partial S(p, r_H)/\partial r_H}{\partial S(p, r_H)/\partial p} \right) dr_H \quad (2-4)$$

In the equation (2-3), $(\partial NI(p, r_F)/\partial r_F)/(\partial NI(p, r_F)/\partial p) dr_F$ represents the change in the price in the import goods market due to the foreign climate policy, which is derived from the total derivatives of net import. Similarly, $(\partial NI(p, r_H)/\partial r_H)/(\partial NI(p, r_H)/\partial p) dr_H$ is the change in the price in the domestic goods market due to the domestic climate policy. Using the equations (2-3) and (2-4), we comprehend the competitiveness effect that a domestic policy has on net imports.

Note that Aldy and Pizer (2011) show that such a reflection remains effective within the range that an increase in marginal cost is the same for domestic and foreign producers and represents their two perceptions. These perceptions are that environmental economics suggests that harmonized carbon regulation should remain effective and that harmonized carbon regulation across energy intense sectors in developed countries is assumed to increase the marginal cost of

production to a similar extent. The border measure is based on their first suggestion, and it is appropriate for climate policy analysis. However, we need to interpret it carefully for this study because my data includes developing countries.

2 Empirical Analysis and Data

2.1 Model

I am interested in the magnitude of the competitiveness effect and measure it using the regression coefficient of (2-4). This is the difference of net imports as a dependent variable and the surrogate variable of domestic climate policy as an explanatory variable. The relation of net imports and domestic policy is²

$$\frac{\partial NI}{\partial r_H} = (S + NI) \left(\frac{\partial \log D}{\partial r_H} \right) - S \cdot \frac{\partial \log S}{\partial r_H} \quad (3-5)$$

From (3-5), there are two approaches to estimate the magnitude: an estimation between the separated demand and supply or of a single net import. I use the separated demand and supply functions, as net import data can have a negative value.

2.2 Parametric and Semi-Parametric Estimations

My regression model is a reduced form of demand and supply. The specification is

$$\log Z_{it}^{(j)} = \alpha_{ij} + \alpha_{it} + \beta \log r_{it}^H + \gamma \log X_{it} + \epsilon_{it}^j \quad (3-6)$$

where $z_{it}^{(j)}$ is demand ($j = D$) and supply ($j = S$) for sector i and year t , r_{it}^H is a proxy variable of domestic climate policy, X_{it} is a matrix of additional regressors that are determinants of demand and supply, and $\epsilon_{it}^{(j)}$ is an error term. The parameters to be estimated are α_{ij} of a fixed effect for sector j , α_{it} of a fixed effect for year t , γ of additional regressors, and β of a competitive effect.

There are several ways to estimate simultaneous equations models. My study applies Seemingly Unrelated Regressions (SUR), which was used in Aldy and Pizer (2011). I consider correlated disturbances across demand and supply equations. Two equations are expressed as a reduced form and the definition of demand and supply data, and the problem identification is clear.

The proxy for the domestic climate policy has several possible variables. Aldy and Pizer (2011) adopt the price of electricity because they consider electricity the majority of energy expenditure in US manufacturing sectors. I use both electricity and heat price as a proxy for domestic climate policy. Heat refers to the transfer of energy between sources and the disposition of heat produced for sale. A majority of the heat included in my data results from the combustion of fuels, although

² Using the definition of total differentiation of a logarithmic function.

small amounts are produced from electrically powered heat pumps and boilers. Additionally, in some cases, only a combination of electricity and heat consumption were available in my data set. This energy price, as well as other data, are constructed and explained in the following subsection (see Section 3.3).

Analyzing the relation between domestic climate policy and demand and supply, we consider semi-parametric models, as well as SUR. This is because there are specifications without a significant estimator in some sample countries. Utilizing the definition of β , which is energy price elasticity of the j function, we reform the relation as the following

$$el_{it}^j = s(\iota_{it}) + \gamma' X_{it} + \alpha'_{it} + \alpha'_{jt} \quad (3-7)$$

where $el_{it}^{(j)}$ is energy price elasticity of the j function, ι_{it} is energy intensity in industry i , and X_{it} is a matrix of additional regressors. $s(\iota_{it})$ is a function that transforms the predictor variable of ι_{it} .

2.3 Data

Data on major countries are widely used in the literature; however, these studies lack either industry level data or data from developing countries and instead focus only on the Organisation for Economic Co-operation and Development (OECD) countries (see Managi et al. (2009) and Fujii and Managi (2013)). The World Input-Output Database (WIOD) was utilized for this analysis. The WIOD consists of four parts: the international input output (IO) table, the national IO table, and socio economic and environmental satellite accounts. WIOD covers the years 1995 to 2009 and 40 developed and developing countries (see Table 2-1).

I define demand as production plus net import, according to Aldy and Pizer (2011). Production and net import are derived from the national IO table. Tariff data and additional regressors used to determine demand and supply were also derived from the table. However, the table does not include tariff data for China, Indonesia, Japan, or the US. I used the IO tables that were offered from the agencies of Japan and the US to construct alternative tariff data. The IO tables of China and Indonesia were not available for this analysis because these IO tables are insufficient with regard to sample period and sectors. Therefore, we used the average tariff from the World Trade Organization's (WTO) tariff database (<http://tariffdata.wto.org/>). The WTO database provides us with more refined classification than my sample set, which includes the related tariff data by 6-digit level of HS code. I aggregated the WTO tariff data to match the classification of the national IO tables.

Energy price data were constructed using the supply and use tables and environmental accounts available in the WIOD database. The output of electricity and heat producers for each industrial activity, measured in US dollars, is included in the supply and use table, and gross energy supply and use are based on the IEA energy balance table, which are included in the environmental

accounts³. The outputs to activities are divided by gross electricity and heat uses of the industrial sectors to obtain each activity's price of electricity and heat.

I use capital compensation, hour and labor compensation worked by three skill types, and the price index of intermediate inputs and gross value added as determinants of demand and supply. These data are also contained in the socio-economic accounts of WIOD.

Tariff data for China, Indonesia, Japan, and the US were not used for this analysis due to missing data. I substituted the other statistics for those missing data. These alternatives are from tariff data for China and Indonesia and from an input output table for Japan and the US. The source of the tariff data is an average of all ad valorem duties from WTO, and we aggregate them in accordance with the sectoral boundary of WIOD. The input output tables for Japan and the US are used in place of the tariff data.

<Table 2-1>

2.4 Result of SUR Estimation

This study estimates the demand and supply functions in each country by SUR estimation using panel data. I used alternative models to have a statistically significant coefficient of energy price, as we focused on the relation between each regressor and energy price from the previous section. Table 2-2 summarizes some of these estimation results, which are based on Models 1, 2, 3, and 4.

I applied a fixed time and group effects model to Model 1 and Model 2 for consideration of a time-specific effect. In Model 3 and Model 4, we applied interaction terms of the energy price and year dummy. I added the interaction terms to consider the variation of crude oil price between the sample periods, which increased to new high levels during the period. Model 1 and Model 3 describe the linear relation between each regressand and energy price, whereas Model 2 and Model 4 capture the impact of energy intensity on demand and supply in each industry, with product terms of a logarithmic energy price and energy intensity.

Moreover, there are two main differences between my estimations and those of Aldy and Pizer (2011). They considered a fuel switching from petroleum to coal within the US, which was encouraged by higher energy prices from 1974 to 1985. Table 2-2 presents estimates of Model 1 to Model 4 for China, Germany, India, Japan, Russia, and the US, which are a part of this analysis. The amounts of their CO₂ emissions account for over 60% of the world total in 2008⁴. The elasticity of demand and supply with respect to energy price, which is negative and statistically significant, is obtained using Models 2, 3 and 4 in Germany. Model 3 in Russia also obtains an

³ Gross energy use records both input and output energy as energy use. Thus, energy use of energy transformation sectors is larger than actual energy. The actual energy use for the sector is input energy, which is transformed into other energy.

⁴ From IEA, CO₂ emissions from fuel combustions in 2008.

estimation of elasticity that is consistent with the expected signs but is not statistically significant. The elasticity in other countries is neither statistically significant nor consistent with the expected sign.

The elasticity of both demand and supply with respect to energy price is expected to decline with an increase in energy intensity. Therefore, estimations of the product term in Models 2 and 4 are expected to be negative. The product term of both demand and supply in Russia and Japan is found to be negative. The estimation of the term in Japan is statistically significant, while the product term of demand in Russia is not. The estimations in the other countries are less clear, so we applied alternative estimation techniques as used for the main results in Aldy and Pizer (2011).

<Table 2-2>

I utilized another technique of semi-parametric regression to estimate the competitiveness effect. This is because the estimation of the energy price elasticity of both demand and supply in the previous subsection falls short of explaining the impact of the climate regulation the impact of the climate regulation.

The semi-parametric estimation model is described in (3-7). The elasticity is derived from the demand and supply regression model, as in Aldy and Pizer (2011). Taking the partial derivatives of an estimation model, including the interaction terms of a logarithmic energy price and energy intensity, with respect to a logarithmic energy price, the energy price elasticity of both demand and supply is a function of energy intensity. The elasticity in (3-7) is used as the dependent variable. I were confronted by a difficulty in using the elasticity as the dependent variable from the demand and supply regression model across all 40 countries. This difficulty comes from unclear results of interaction terms in most countries. I make use of other ways to generate the energy price elasticity for the semi-parametric estimation. I generate the elasticity from the ratio of either one-period lagged value of logarithmic demand or supply or use one of the logarithmic energy prices as a substitute for the values (3-7). However, the energy price elasticity of both demand and supply functions are used when the sign condition of the product term in each demand and supply is met, and we use the results of Model 2 in Table 2-2 as the elasticity of the demand and supply functions.

Figure 2-1 is the scatter plot of the differences of elasticity of demand and supply and energy intensity for all sectors across all forty countries. The right panel shows the relation in 1996, and the left panel shows it in 2009. The difference of elasticity ranges from negative to positive. Compared to 1996, the average energy intensity in 2009 is higher, and the standard deviation is also higher. The difference of elasticity in 2009 marks a positive average from a negative value in 1996, and the standard deviation in 2009 is smaller than 1996.

Figure 2-2 shows the results of semi-parametric regression of the data from these countries. The horizontal axis in these graphs presents the energy intensity, and the vertical axis shows the difference of energy price elasticity of demand and supply. The lines in these graphs show the outputs of the regression function, and the shading shows a pointwise 95% confidence band for

energy intensity, which is one of the predictor variables in this GAMs model. The significant narrow bands for the predictors in Japan and Russia largely stem from the procedure used to generate the energy price elasticity of demand and supply, a dependent variable in this GAMs model. That is to say, the variables for those countries, except Japan and Russia, are generated by the ratio of one-period lagged value between logarithmic demand and supply and logarithmic energy price. Some of these variables undergo a wide change when either demand and supply or energy price irregularly moves from the previous year, but we utilized these variables as long as it was clear that the data were not outliers.

Heavy industry features a higher energy intensity and is more apt to be subject to carbon emission constraints. Energy-intensive products are relatively essential goods for downstream industries, and energy price elasticity of demand is thought to be inelastic. The heavy industries, as well as their suppliers, are sensitive to energy price input; however, their investment is vast, and it takes quite a few years to replace their facilities. Thus, energy price elasticity of supply is thought to be slightly elastic. The energy price elasticity function of an energy intensive industry is expected to be a decreasing function, and the change rate in the slope of the function is expected to be a gradual increase.

The differences in energy price elasticity in Japan and Russia are decreasing functions, and China and the US are decreasing in most ranges. In Japan and Russia, the slope of the difference is negative, and the value of the difference for energy intensive sectors is negative. This is because the elasticity of supply is lower than the elasticity of demand in these two countries. In Japan, industrial sectors took the opportunity to improve energy efficiency following the oil crisis. Countries that have improved energy efficiency do not have to reduce production in response to rising energy prices; thus, the energy price elasticity of supply in these countries may be low. This is because high energy efficiency leads to production with low energy costs. Thus, the difference of elasticity of demand and supply in this country is positive, and the absolute value is large.

<Figure 2-1>

<Figure 2-2>

3 Simulations

Several major developed and developing countries implemented climate-related mitigation policies before the accord of global agreement. Note that global agreement remains widely recognized for its significance as a tool for resolution of the long-term international environmental problems, and its success will require the engagement of multiple countries (IPCC 2001 and 2007). The country-specific policies resulting from these circumstances may impede a harmonized global agreement that is both environmentally sound and cost-effective. The economic incentives that most nations have already installed or addressed may play a central role in global emission reduction. It is significant to consider the effect of national regulation in a global context, as well as

recognize the domestic impact of policies implemented in other countries .

I use the results of this estimation to consider the impact of climate change policy. The main mitigation policy is to impose an additional cost on fossil fuel, whose combustion results in an emission of CO₂. Here, we assume that the cost is reflected in the price of electricity and heat. Electricity and heat are major energy components for most manufactures and proxies for fossil fuel. The main source of electricity and heat is from fossil fuel, such as coal-fired power plants and combined heat and power plants.

An additional carbon price of \$15 per CO₂ is set in this study, and the US Environmental Protection Agency analysis (EPA, 2010) is used for reference. The analysis is conducted to estimate the economic and environmental effects of the American Power Act. The act was put before the US Congress in 2010 and aimed to cut GHG emissions and reliance on fossil fuels in the US. The allowance price is projected to range from \$16 per CO₂ equivalent (CO₂e) to \$17 per CO₂e in 2013 in the analysis. I applied a carbon tax of \$15 per CO₂ on countries other than US because several bills to address climate change in the US includes border adjustment⁵. The border adjustment results in other countries sharing the burden of CO₂ reduction at levels comparable to the US burden. In the US, regulatory costs are regarded as a usual cost of doing business and part of the global cost of CO₂ reduction.

I evaluate CO₂ emissions from electricity and heat use by countries and measure carbon tax per unit of electricity and heat use, which is equivalent to \$15 per CO₂e. In my simulation, domestic climate regulation is estimated as the sum of the energy price of electricity and heat in 2009 and the carbon tax per unit of energy. I cannot obtain all the estimation results to meet requirements in 6 major emitters, and the scope of my consideration for climate regulation is limited in industrial sectors and countries.

The competitiveness effect is defined as the equilibrium difference of domestic supply change between the presence of domestic and foreign climate policy, and the presence of only domestic climate policy. From (3-5) the competitiveness effect is measured as the difference of energy price elasticity of demand and supply. The estimation results of the difference are shown in the previous section. Table 2-3 sums up the competitiveness effect of energy intensive sectors in all countries. I consider the effect of regulation on net import, $NI(\partial \ln D / \partial r)$ (see (3-5)). Compared to Aldy and Pizer (2011), who analyzed the US competitiveness effect, my result, with a weighted average of 0.5, is slightly smaller than their result, with an all sector competitive effect of 0.7.

Table 2-4 shows the results of industry rating on the competitiveness effect, which is a production weighted average. I find that some energy intensive industries, as well as some service sectors, hold the competitiveness effect. Compared with industrial materials manufacturing,

⁵ The American Power Act requires importers to submit allowances under certain conditions, which is called International Reserve Allowance Program. A similar article is included in the Clean Energy Jobs and American Power Act in 2009.

product manufacturing, a relatively power intensive industry, shows sensitivity to energy price. The maximum impact is 1.32, and the impacts of 19 sectors are less than one; moreover, the effects are not particularly large. From (3-5), the competitiveness effect is regarded as the effect of a regulation on net imports, suggesting the possible impact of substituting an imported good for a domestic product on the implementation of domestic regulations. These results suggest that a policy to protect particular industries from trade competition outside a country is less effective, and we find that an industrial protection policy is unsupportable in the global and US markets.

Table 2-5 shows the country ratings by competitiveness effect, based on a production weighted average. Almost all resulting positive values are less than one, although Bulgaria and Canada are considerably higher. The countries that have a low competitiveness effect are less incentivized to implement domestic regulations. However, there are some countries whose macro-economies would be positively affected by domestic regulation, while a global agreement would have a limiting effect.

I consider the results in the light of a global climate agreement. The larger the competitiveness effect, the more impact it has on supply due to inelastic supply with respect to energy price. Such inelasticity is typified by energy intensive industries. Ideally, when considering a global agreement to mitigate the competitiveness effect, it would also be meaningful to discuss an international program to increase energy efficiency.

<Table 2-3>

<Table 2-4>

<Table 2-5>

4 Concluding Remarks

Reduction of fossil fuel is crucial in the face of increasing crude oil prices and global climate change. When a climate policy is enforced in one country, it is important to consider the policies that have been implemented by other major countries to reduce fossil fuel consumption. Aldy and Pizer (2011) provide a valid argument for such a case. This is different from many previous studies that focus on what happens when other countries have not introduced such policies. I consider the impact of climate regulation on the industries in major developing and developed countries following a methodology developed by Aldy and Pizer (2011).

Comparing this analysis with their study, we expanded the scope from the only US to include forty major countries. My results show that some industries and countries have competitiveness effects, although the impacts are not particularly large. It is possible to substitute an imported product for a domestic good in some sectors to implement domestic regulation; however, protection from trade competition is less effective for particular industries.

I find that some countries have a relatively high competitiveness effect, and the macro-economy

of these countries would possibly be affected by domestic regulations. A global agreement would be helpful in buffering the reduction in production for these countries.

My discussion is limited by space; however, developed countries are prone to inelastic supply with respect to energy price and have the ability to maintain their competitiveness. Therefore, in these countries, a global agreement on the treatment of climate change would be more effective in averting the reduction of production than a domestic policy.

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TABLE

Table 2-1 List of the countries

European Union (27)	Hungary	Slovenia	Taiwan
Austria	Ireland	Spain	Turkey
Belgium	Italy	Sweden	Indonesia
Bulgaria	Latvia	United Kingdom	
Cyprus	Lithuania		North America (2)
Czech Republic	Luxembourg	Asia and Pacific (9)	Canada
Denmark	Malta	Japan	United States
Estonia	Netherlands	Australia	
Finland	Poland	Russia	Latin America (2)
France	Portugal	China	Brazil
Germany	Romania	India	Mexico
Greece	Slovak Republic	South Korea	

Note: The figure in parentheses is the number of countries

Table 2-2 SUR estimation results

	China							
	Model 1		Model 2		Model 3		Model 4	
	Demand	Supply	Demand	Supply	Demand	Supply	Demand	Supply
ln(Energy Price)	0.304 *** (0.03)	0.2854 *** (0.026)	0.1435 *** (0.042)	0.1721 *** (0.037)	0.2462 *** (0.036)	0.2254 *** (0.032)	-0.0643 *** (0.056)	-0.0067 *** (0.05)
ln(Energy Price) x Energy Intensity			0.0204 *** (0.004)	0.0144 *** (0.003)			0.0304 *** (0.004)	0.0227 *** (0.004)
ln(Tariff)	-0.1184 ** (0.046)	-0.2062 *** (0.04)	-0.1164 *** (0.044)	-0.2049 *** (0.039)	-0.1495 *** (0.05)	-0.2386 *** (0.044)	-0.215 *** (0.048)	-0.2875 *** (0.043)
ln(Capital Share)	0.4873 *** (0.033)	0.4816 *** (0.029)	0.4757 *** (0.032)	0.4733 *** (0.028)	0.4929 *** (0.034)	0.4881 *** (0.029)	0.455 *** (0.032)	0.4597 *** (0.029)
ln(Labour Reward)	-0.1529 *** (0.043)	-0.1324 *** (0.038)	-0.1391 *** (0.042)	-0.1227 *** (0.037)	-0.1546 *** (0.044)	-0.1343 *** (0.038)	-0.1545 *** (0.041)	-0.1342 *** (0.036)
Industry dummy	yes	yes	yes	yes	yes	yes	yes	yes
Year dummy	yes	yes	yes	yes	yes	yes	yes	yes
Number of Observations	386		386		386		386	
R-square	0.986	0.988	0.987	0.989	0.986	0.988	0.988	0.989
F-Stat	503	611	531	628	488	588	547	634

	Germany							
	Model 1		Model 2		Model 3		Model 4	
	Demand	Supply	Demand	Supply	Demand	Supply	Demand	Supply
ln(Energy Price)	0.069 *** (0.018)	0.0157 *** (0.017)	0.0202 *** (0.017)	-0.0306 * (0.016)	0.0258 *** (0.02)	-0.0279 *** (0.019)	-0.0448 ** (0.02)	-0.0946 *** (0.018)
ln(Energy Price) x Energy Intensity			0.0173 *** (0.002)	0.0164 *** (0.002)			0.0187 *** (0.002)	0.0177 *** (0.002)
ln(Tariff)	0.4378 *** (0.027)	0.5231 *** (0.025)	0.3692 *** (0.026)	0.458 *** (0.024)	0.4555 *** (0.027)	0.5359 *** (0.025)	0.3749 *** (0.026)	0.4598 *** (0.024)
ln(Capital Share)	0.0822 *** (0.013)	0.0942 *** (0.012)	0.0693 *** (0.012)	0.082 *** (0.011)	0.0779 *** (0.013)	0.0919 *** (0.012)	0.0711 *** (0.012)	0.0855 *** (0.011)
ln(Labour Reward)	-0.1836 ** (0.08)	-0.1457 * (0.074)	-0.1843 ** (0.073)	-0.1463 ** (0.067)	-0.1713 ** (0.081)	-0.1292 * (0.075)	-0.1692 ** (0.074)	-0.1273 * (0.067)
Industry dummy	yes	yes	yes	yes	yes	yes	yes	yes
Year dummy	yes	yes	yes	yes	yes	yes	yes	yes
Number of Observations	460		460		460		460	
R-square	0.986	0.992	0.988	0.993	0.985	0.992	0.988	0.993
F-Stat	578	980	685	1173	552	954	659	1151

	India							
	Model 1		Model 2		Model 3		Model 4	
	Demand	Supply	Demand	Supply	Demand	Supply	Demand	Supply
ln(Energy Price)	0.4389 *** (0.045)	0.3617 *** (0.04)	0.4381 *** (0.046)	0.3602 *** (0.041)	0.0542 *** (0.083)	0.1183 *** (0.075)	0.0566 *** (0.084)	0.1186 *** (0.075)
ln(Energy Price) x Energy Intensity			0.0007 *** (0.01)	0.0013 *** (0.009)			-0.003 *** (0.011)	-0.0005 *** (0.01)
ln(Tariff)	0.0969 *** (0.018)	0.1007 *** (0.016)	0.0969 *** (0.018)	0.1006 *** (0.016)	0.1097 *** (0.019)	0.1224 *** (0.017)	0.1099 *** (0.019)	0.1224 *** (0.017)
ln(Capital Share)	0.4635 *** (0.028)	0.553 *** (0.024)	0.4635 *** (0.028)	0.553 *** (0.024)	0.5283 *** (0.029)	0.5978 *** (0.026)	0.5284 *** (0.029)	0.5978 *** (0.026)
ln(Labour Reward)	-0.2219 *** (0.042)	-0.2047 *** (0.037)	-0.2221 *** (0.042)	-0.2049 *** (0.037)	-0.2088 *** (0.04)	-0.1722 *** (0.036)	-0.2085 *** (0.04)	-0.1721 *** (0.036)
Industry dummy	yes	yes	yes	yes	yes	yes	yes	yes
Year dummy	yes	yes	yes	yes	yes	yes	yes	yes
Number of Observations	439		439		439		439	
R-square	0.978	0.982	0.978	0.982	0.974	0.978	0.974	0.978
F-Stat	362	449	353	438	310	369	303	361

(...continued)

	Japan							
	Model 1		Model 2		Model 3		Model 4	
	Demand	Supply	Demand	Supply	Demand	Supply	Demand	Supply
ln(Energy Price)	0.096 *** (0.022)	0.0594 *** (0.02)	0.0559 ** (0.022)	0.0283 (0.021)	0.2117 *** (0.047)	0.2484 *** (0.043)	0.1159 ** (0.048)	0.1792 *** (0.045)
ln(Energy Price) x Energy Intensity			-0.3175 *** (0.063)	-0.246 *** (0.059)			-0.3519 *** (0.061)	-0.2542 *** (0.057)
ln(Tariff)	-0.0023 (0.033)	-0.0079 (0.031)	0.0056 (0.032)	-0.0018 (0.03)	0.022 (0.031)	0.0274 (0.029)	0.0169 (0.03)	0.0238 (0.028)
ln(Capital Share)	0.3024 *** (0.028)	0.3782 *** (0.026)	0.2834 *** (0.027)	0.3634 *** (0.025)	0.3115 *** (0.028)	0.382 *** (0.025)	0.2835 *** (0.027)	0.3618 *** (0.025)
ln(Labour Reward)	0.0494 (0.064)	-0.0982 * (0.059)	0.0892 (0.062)	-0.0674 (0.058)	0.0051 (0.064)	-0.1272 ** (0.059)	0.0576 (0.062)	-0.0893 (0.058)
Industry dummy	yes	yes	yes	yes	yes	yes	yes	yes
Year dummy	yes	yes	yes	yes	yes	yes	yes	yes
Number of Observations	407		407		407		407	
R-square	0.980	0.989	0.981	0.989	0.980	0.989	0.981	0.990
F-Stat	371	682	389	698	358	667	383	688

	Russia							
	Model 1		Model 2		Model 3		Model 4	
	Demand	Supply	Demand	Supply	Demand	Supply	Demand	Supply
ln(Energy Price)	0.0342 * (0.019)	0.0643 *** (0.016)	0.0392 * (0.021)	0.081 *** (0.017)	-0.0503 ** (0.025)	-0.0131 (0.021)	-0.0317 (0.026)	0.0075 (0.021)
ln(Energy Price) x Energy Intensity			-0.00002 (0.00003)	-0.00006 ** (0.00003)			-0.0001 *** (0.00004)	-0.0002 *** (0.00003)
ln(Tariff)	0.2207 *** (0.024)	0.2998 *** (0.02)	0.2218 *** (0.024)	0.3035 *** (0.02)	0.2485 *** (0.026)	0.3235 *** (0.022)	0.239 *** (0.026)	0.313 *** (0.022)
ln(Capital Share)	0.3633 *** (0.028)	0.3373 *** (0.023)	0.3633 *** (0.029)	0.3373 *** (0.023)	0.4286 *** (0.03)	0.4038 *** (0.025)	0.4129 *** (0.03)	0.3865 *** (0.025)
ln(Labour Reward)	-0.432 *** (0.121)	0.0409 (0.1)	-0.4286 *** (0.122)	0.0521 (0.1)	-0.4212 *** (0.131)	0.0211 (0.111)	-0.4122 *** (0.13)	0.031 (0.108)
Industry dummy	yes	yes	yes	yes	yes	yes	yes	yes
Year dummy	yes	yes	yes	yes	yes	yes	yes	yes
Number of Observations	472		472		472		472	
R-square	0.974	0.987	0.974	0.987	0.970	0.984	0.971	0.985
F-Stat	325	648	318	641	274	525	276	539

	United States							
	Model 1		Model 2		Model 3		Model 4	
	Demand	Supply	Demand	Supply	Demand	Supply	Demand	Supply
ln(Energy Price)	0.0999 *** (0.017)	0.1132 *** (0.021)	0.0224 (0.019)	0.0261 (0.023)	0.0983 *** (0.024)	0.1092 *** (0.03)	0.033 (0.024)	0.0341 (0.03)
ln(Energy Price) x Energy Intensity			0.0438 *** (0.006)	0.0492 *** (0.007)			0.0445 *** (0.006)	0.0513 *** (0.007)
ln(Tariff)	0.3593 *** (0.061)	0.3203 *** (0.076)	0.29 *** (0.056)	0.2424 *** (0.071)	0.3536 *** (0.061)	0.3172 *** (0.076)	0.2709 *** (0.058)	0.2219 *** (0.072)
ln(Capital Share)	0.4363 *** (0.023)	0.5572 *** (0.029)	0.3774 *** (0.023)	0.4911 *** (0.029)	0.4394 *** (0.024)	0.5589 *** (0.029)	0.379 *** (0.023)	0.4894 *** (0.029)
ln(Labour Reward)	-0.388 *** (0.064)	-0.5676 *** (0.08)	-0.3104 *** (0.06)	-0.4804 *** (0.076)	-0.3873 *** (0.065)	-0.5683 *** (0.08)	-0.3051 *** (0.061)	-0.4737 *** (0.076)
Industry dummy	yes	yes	yes	yes	yes	yes	yes	yes
Year dummy	yes	yes	yes	yes	yes	yes	yes	yes
Number of Observations	360		360		360		360	
R-square	0.978	0.979	0.981	0.982	0.977	0.979	0.981	0.982
F-Stat	320	339	374	382	307	329	356	371

Note: Estimations include the fixed effects of year and industrial sectors.

Table 2-3 Impact of carbon tax on the major energy intensive sector, by country

	Australia	Austria	Belgium	Bulgaria	Brazil	Canada	China	Cyprus	Czech Republic	Germany
Pulp, Paper, Paper , Printing and Publishing	-0.757	2.236	3.594	51.223	0.459	-21.100	-0.354	2.734	0.024	-0.772
Coke, Refined Petroleum and Nuclear Fuel	-3.308	10.560	8.302	62.297	-	6.410	-0.466	-	0.000	-4.909
Chemicals and Chemical Products	-2.250	4.945	7.142	-330.824	-0.151	9.133	-0.503	-3.253	-1.147	-1.087
Rubber and Plastics	2.860	0.622	-0.335	-26.167	-0.265	11.742	0.092	-3.765	-0.089	-0.176
Other Non-Metallic Mineral	-0.222	3.802	5.913	22.638	0.052	14.393	-0.843	-4.607	-0.171	-0.537
Basic Metals and Fabricated Metal	2.981	1.872	4.004	-39.133	1.135	-30.102	-0.848	1.559	-0.007	-0.309
Average of all sectors	0.020	4.268	-1.306	22.437	-0.022	6.357	0.131	0.389	-0.035	0.054
	Denmark	Spain	Estonia	Finland	France	United Kingdom	Greece	Hungary	Indonesia	India
Pulp, Paper, Paper , Printing and Publishing	1.212	0.122	0.192	1.320	0.611	2.578	-0.786	3.533	2.355	0.452
Coke, Refined Petroleum and Nuclear Fuel	0.000	-0.399	27.044	-0.062	-2.082	0.000	-0.308	-12.436	-	-
Chemicals and Chemical Products	-0.238	0.061	13.923	-0.219	0.326	6.798	8.175	-52.171	3.743	0.524
Rubber and Plastics	1.102	0.439	-2.610	0.040	-1.187	11.010	-0.092	-1.166	-0.716	0.283
Other Non-Metallic Mineral	-0.738	0.848	0.051	0.152	6.741	10.619	2.706	0.972	1.033	0.240
Basic Metals and Fabricated Metal	1.122	2.034	-0.346	0.105	2.435	4.593	-1.267	-2.194	-28.683	0.333
Average of all sectors	0.676	-0.147	-0.027	-0.046	-1.190	4.463	0.217	-0.118	-0.114	-0.035
	Ireland	Italy	Japan	Korea	Lithuania	Luxembourg	Latvia	Mexico	Malta	Netherlands
Pulp, Paper, Paper , Printing and Publishing	-0.386	0.934	0.061	-2.422	0.383	-0.025	0.518	0.084	-0.093	-0.105
Coke, Refined Petroleum and Nuclear Fuel	2.291	0.924	0.259	-0.344	-0.003	-	-	-0.004	-	-0.242
Chemicals and Chemical Products	-0.601	1.059	0.042	0.796	0.859	2.596	0.552	-0.150	0.083	0.614
Rubber and Plastics	-0.663	0.944	0.280	-0.654	0.194	0.016	0.895	-0.148	-0.708	-0.055
Other Non-Metallic Mineral	-0.660	0.871	-0.019	-5.971	0.198	-0.082	-0.560	0.514	0.153	-0.144
Basic Metals and Fabricated Metal	-0.508	0.612	-0.254	-1.558	0.842	0.810	0.153	0.369	0.071	0.003
Average of all sectors	0.004	-0.010	0.008	0.089	0.063	-0.006	0.177	0.064	0.095	-0.023
	Poland	Portugal	Romania	Russia	Slovak Republic	Slovenia	Sweden	Turkey	Taiwan	United States
Pulp, Paper, Paper , Printing and Publishing	0.065	-6.527	0.785	-0.016	-0.074	-0.672	-0.013	-0.044	-1.800	-1.577
Coke, Refined Petroleum and Nuclear Fuel	0.110	1.078	-2.141	-0.037	-0.317	0.000	0.101	0.891	4.701	0.643
Chemicals and Chemical Products	2.368	12.433	-24.978	-0.035	0.211	0.358	0.059	0.260	-17.838	-2.474
Rubber and Plastics	0.151	-1.311	0.504	0.007	-1.179	-3.582	-0.163	2.410	8.971	1.242
Other Non-Metallic Mineral	0.043	-3.681	-0.101	-0.006	-0.507	-16.503	-0.002	3.831	-22.704	-2.306
Basic Metals and Fabricated Metal	0.102	0.013	-1.164	-0.019	0.418	-8.423	0.047	3.946	-15.520	-2.620
Average of all sectors	-0.014	0.084	-0.044	-0.001	-0.573	2.158	-0.059	0.635	-0.838	-0.018

Table 2-4 Sector rating of competitive effect

Sectors	Weighted Average	Sectors	Weighted Average	Sectors	Weighted Average	Sectors	Weighted Average
1 Leather etc.	1.320	11 Other Transport	0.882	21 Elec. & Optical Equipment	0.502	31 Electricity, Gas and Water	-0.535
2 Finance	1.313	12 Other H&S Coke,	0.834	22 Textiles etc.	0.481	32 Basic Metals	-1.337
3 Other Manufacturing	1.287	13 Refinery, Nuclear fuel	0.832	23 Public	0.327	33 Pulp, Paper etc.	-1.386
4 Post & Telecoms	1.236	14 Machinery	0.815	24 Farm & Marin	0.149	34 Mining etc.	-3.227
5 Construction	1.072	15 Motor Vehicle etc	0.744	25 Air Transport	0.055		
6 Other Business	1.012	16 Retail Trade	0.694	26 Hotels & Restaurants	-0.088		
7 Transport Equipment	0.949	17 Food & Tobacco Wholesale	0.658	27 Education	-0.180		
8 Inland Transport	0.929	18 (except automobile)	0.641	28 Chemical	-0.194		
9 Rubber & Plastics	0.904	19 Wood	0.623	29 Non-Metallic Mineral	-0.252		
10 R.E.	0.894	20 Health & Social Work	0.590	30 Water Transport	-0.343		

Note: The values are a weighted average using national production in each sector as a weight. "R.E." means real estate. The competitiveness effect is defined as the equilibrium difference of domestic supply change between the presence of domestic and foreign climate policy and the presence of only domestic climate policy.

Table 2-5 Country ratings of competitive effect

Country	Weighted Average	Country	Weighted Average	Country	Weighted Average	Country	Weighted Average
1 Bulgaria	39.872	11 Germany	0.355	21 Brazil	0.055	31 Czech Republic	-0.127
2 Canada	8.546	12 Turkey	0.339	22 France	0.038	32 Italy	-0.134
3 Austria	4.718	13 Estonia	0.233	23 Netherlands	0.032	33 Spain	-0.269
4 United Kingdom	3.723	14 Malta	0.204	24 Japan	0.010	34 Indonesia	-0.328
5 Taiwan	1.718	15 Latvia	0.168	25 Russia	0.002	35 Slovenia	-0.442
6 Cyprus	0.711	16 China	0.140	26 Mexico	-0.018	36 Romania	-0.783
7 Denmark	0.556	17 Luxembourg	0.124	27 Finland	-0.026	37 Slovak Republic	-0.784
8 United States	0.501	18 Lithuania	0.120	28 India	-0.060	38 Korea	-2.865
9 Portugal	0.486	19 Poland	0.094	29 Greece	-0.063	39 Belgium	-3.167
10 Australia	0.452	20 Sweden	0.067	30 Ireland	-0.100	40 Hungary	-4.838

Note: The values are weighted averages using sectoral production in each country as a weight.

FIGURE

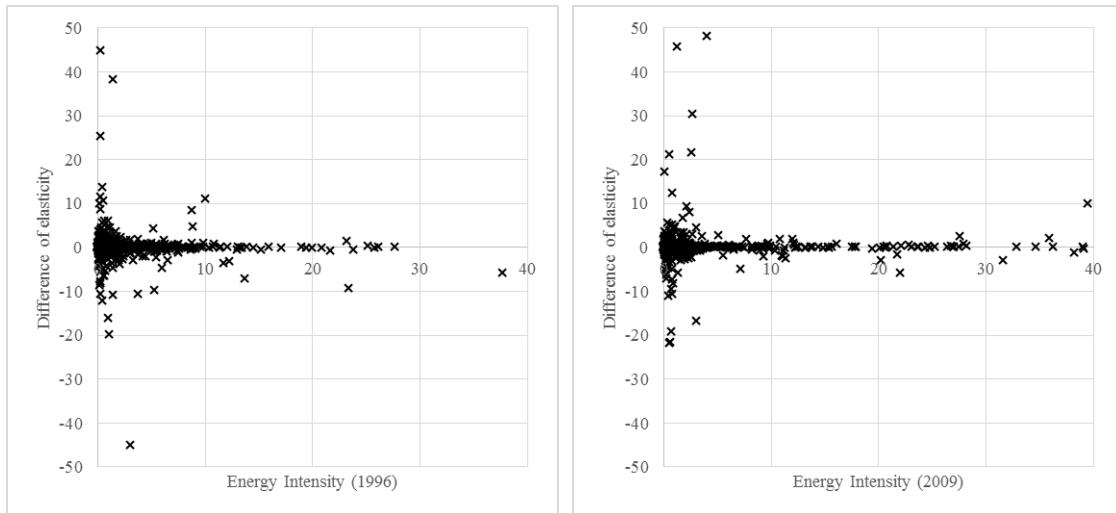


Figure 2-1 Scatter plot of differences in elasticity of demand and supply and energy intensity in 1996 and 2009

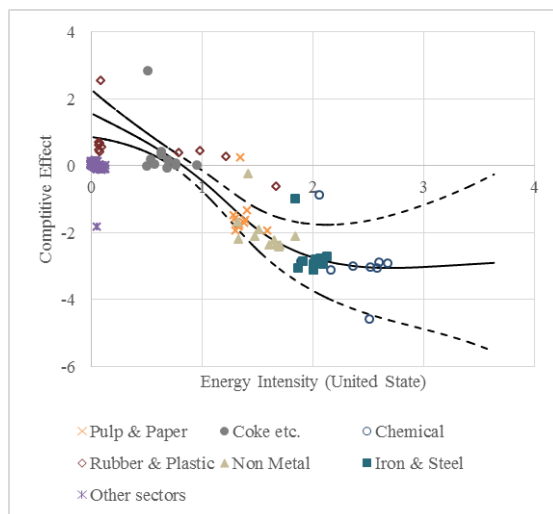
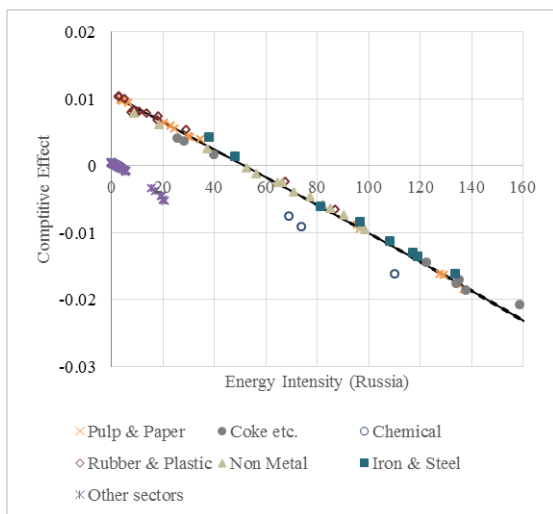
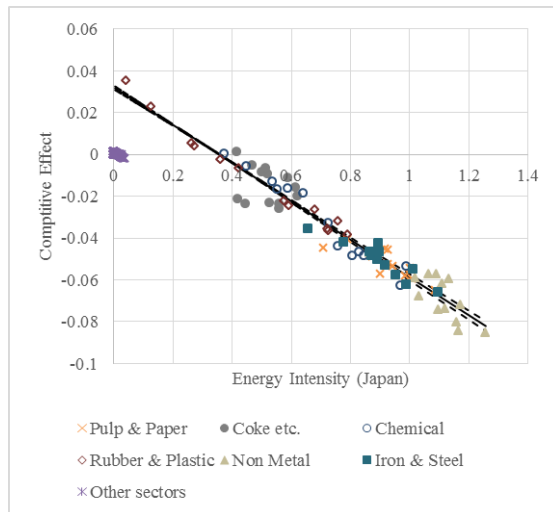
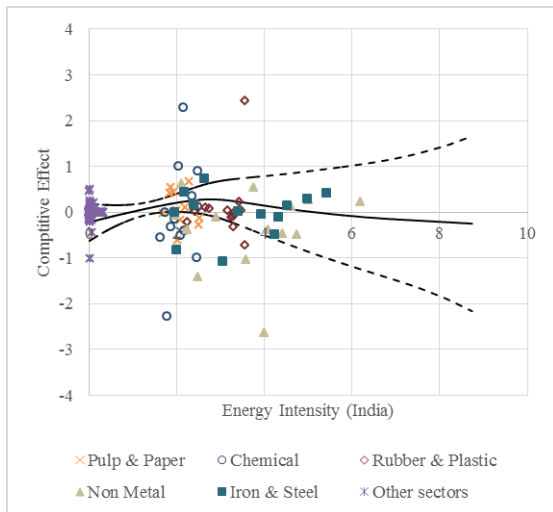
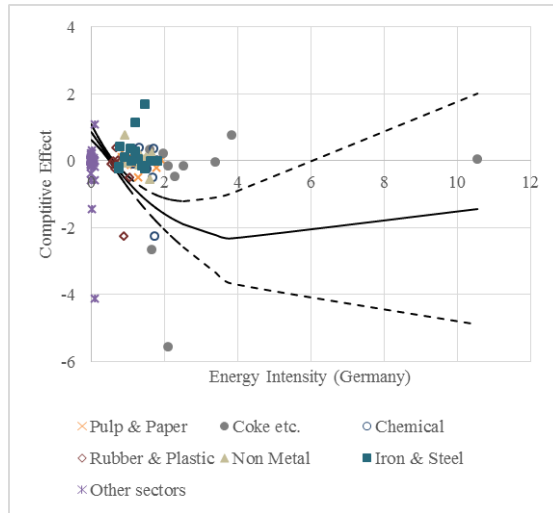
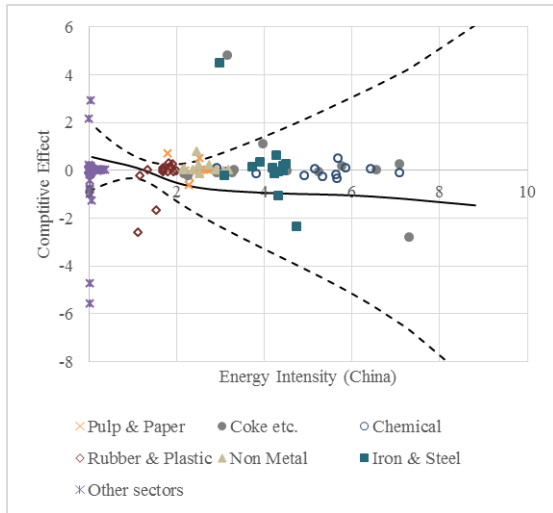


Figure 2-2 Competitive effect: results of semi-parametric regression analysis

Note: Energy price elasticity of both demand and supply in Japan and Russia is generated from (3-7). Energy intensity in 2009 is used as horizontal axis for simplicity. Other sectors show an average value of all sectors, except pulp & paper, coke, chemical, rubber & plastic, non-metal, and iron & steel.

Chapter 3 COMPARATIVE ADVANTAGE OF ENERGY AND ENVIRONMENT

1. Introduction

One of the fundamental questions that drives the literature that connects international trade and the environment is whether trade flow affects environmental aspects, such as environmental quality and regulation, and vice versa. The related literature can be classified into two categories. The first set of literature focuses on whether trade liberation influences environmental quality. The second set concerns how the stringency of environmental regulation in an exporting country affects trade flow. This paper falls into the latter category, but it differs from previous empirical analyses in that I shift the focus of analysis from regulatory effects to the effects of energy efficiency.

The influence of trade on the environment depends on scale, technique, and composition effects (Grossman and Krueger, 1991)¹. Previous empirical analyses have attempted to quantify the influence of these effects (Grossman and Krueger, 1995, Antweiler, Copeland and Taylor, 2001, Cole and Elliott, 2003, Managi, Hibiki and Tsurumi, 2009, McAusland and Millimet, 2013). In contrast, many theoretical and empirical works have studied the impact of environmental regulation on trade flow. The discussions particularly focus on the pollution haven hypothesis², which claims that stringent environmental regulations induce the comparative advantage of less pollution-intensive industries because regulation imposes relatively higher costs on pollution-intensive industries (Ederington and Minier, 2003, Ederington, Levinson and Minier, 2005, Levinson and Taylor, 2008, Managi, Hibiki and Tsurumi, 2009). However, the empirical studies provide little consensus on the relationship between environmental regulation and trade flow.

I focus on environment-related efficiency because the impact of technology that improves environmental externalities has received little attention in the main economics literature, although many economists recognize its vital importance (Carraro, Fay and Galeotti, 2014). Hence, this paper attempts to provide further insight into the roles of resources and the environment in economic activity, particularly in trade. I analyze the relationship between the environment and trade by studying the effect on export performance of environment-related efficiencies, which are measured by energy use (energy efficiency) and pollution emissions (pollution efficiency) as units of production in the exporting country.

My work is closely related to the literature on trade and heterogeneous productivity across industries and firms. The models in the literature show positive relationships between firm scale, capital intensity, and productivity in most countries (Bernard and Jensen, 1999, Pavcnik, 2002, Bernard et al., 2003). In these analyses, productivity plays a central role in understanding the exporting variation among domestic industries as well as among the firms in a specific industry.

¹ Pollution emissions through trade depend on a magnitude relationship between these effects, but a basket of the three effects is generally undetermined in advance because the composition effect is thought to depend on a comparative advantage across countries.

² In addition, the Porter hypothesis is also discussed in the context of the impact of environmental regulations.

The productivity in these models generally refers to total factor productivity, which captures all factors except for capital and labor. I contribute to the literature by quantifying the effect of environment-related efficiency rather than the more conventionally used productivity.

I follow the setup and implication of Costinot, Donaldson and Komunjer (2012), hereafter CDK, which tests a Ricardian comparative advantage based on a theoretical foundation. CDK uses labor per production as productivity. I apply their framework, which connects productivity and trade flow, by replacing the labor productivity in their model with environmental efficiency measured by energy use and emission levels. I test the theoretical implications using the trade flow data and the environment-related efficiency data from the The World Input-Output Database (WIOD). My analysis indicates that the degree of energy and pollution efficiency positively affects export levels across domestic industries.

The remainder of this article is organized as follows. Section 2 reviews previous studies that consider the relationship between trade and the environment and the effect of environmental regulation on trade. Section 3 explains the empirical models and the data. Section 4 provides estimation results. Section 5 discusses the results.

2. Trade, the Environment, and Productivity

This paper attempts to connect trade, energy and pollution efficiency. There are two sets of literature that are particularly relevant to this work. One concerns the impact of the environment on trade, and the other focuses on the relationship between trading patterns and productivity. I review the implications of both sets of studies separately.

2.1 The Environment and Trade

Tobey (1990) empirically showed that environmental regulation had little impact on net exports in the pollution-intensive industries in developed countries³. Similarly, Xu (1999) found that export performance is not particularly affected by variations in the stringency of environmental regulations; the export performance of environmentally sensitive goods was found to be stable between the 1960s and the 1990s, even as environmental standards became more stringent over this period. In contrast, Robison (1988) found a significant impact of environmental regulation on net exports using U.S. trade data. The author's result indicates that a marginal change in abatement cost negatively influences industrial trade volume, and thus the goods with higher abatement costs are imported whereas the goods with lower abatement costs are exported.

Earlier empirical analyses assumed the exogeneity of environmental regulations in trade patterns (Robison, 1988, Tobey, 1990), but recent studies have ruled out such assumptions and addressed the endogeneity between trade patterns and the stringency of regulations⁴. Taking endogeneity into account, the empirical results appear to support the statistically significant

³ Van Beers and Van Den Bergh (1997) highlight that his results were influenced by inaccurate environmental policy indicators in his analysis.

⁴ The reason is that environmental regulation standards are commonly industry specific.

effect of environmental regulations on trading patterns. Ederington and Minier (2003) found that environmental regulation had a positive impact on net imports in the U.S. Their results showed that a usual ordinal least square (OLS) estimation that did not consider endogeneity underestimated the magnitude of the marginal effect of environmental regulation. The empirical results of Levinson and Taylor (2008) also support the possible underestimation of regulatory impact if endogeneity is ignored. Using the data on environmental regulations in the U.S. and net imports to Canada and Mexico, the authors show that the positive impact of abatement costs on net imports from Mexico and the endogeneity-adjusted impact of environmental regulations are larger than the impact of unadjusted models.

The pollution haven hypothesis is popularly discussed and tested in the literature. This hypothesis predicts that the industries that are affected by stringent environmental regulations move to less-regulated environments in order to avoid the added costs from the imposed regulations. The empirical results of analyses that test that hypothesis lack consensus; whereas Antweiler, Copeland and Taylor (2001) and Ederington, Levinson and Minier (2005)⁵ find little support for the hypothesis, Managi, Hibiki and Tsurumi (2009) present empirical evidence that supports the predictions of the pollution haven hypothesis. Not only is the supportive empirical evidence for the hypothesis inconsistent, some argue that the pollution haven may be unrelated to environmental regulations. Chua (2003) built a theoretical model that implies that pollution taxes increase the prices of goods by increasing production costs, which consist of factor prices in a numeraire good and an abatement service.

In order to connect the environment and trade, the previous studies have focused mainly on the effect of environmental regulations on the trade patterns of countries and industries. Where the importance of the regulation effect is typically emphasized, I consider the effect of the environment from a different angle, that of productivity rather than the regulations.

2.2 Trade and productivity

The effect of productivity variation on trade patterns is well documented. The previous studies on trade and firms have indicated a robust relationship between the scale of firm capital intensity, productivity and export performance. Bernard and Jensen (1999) investigated a relationship between exporting and producing at the firm level using census data, and they showed that high-performance firms become exporters but that past export performance does not necessarily boost a firm's current performance. Similarly, Aw, Chung and Roberts (2000) investigated the relationship using plant-level data from Korea and China, and Bernard and Wagner (2001) investigated using German data. Pavcnik (2002) analyzed the impact of tariff reductions on export performance using firm-level data in Chile and showed that tariff reductions encourage firms with

⁵ They made three hypotheses regarding the superficially poor correlation between environmental regulation and trade. They indicated that the extent of the effect of regulatory stringency on trade in the 'footloose' industries is understated and that pollution-intensive industries tend to be relatively immobile.

relatively lower productivity to exit the market. According to that study, exiting firms' productivity is 8 percent lower than the average. Therefore, increased export performance is induced by the increase in average productivity, which is caused by the exit of lower-productivity firms.

One of the consistently observed facts is that the productivity of an engaged exporting firm is greater than that of firms that only operate in the domestic market⁶. The measure of productivity that is used in these studies is either estimated total factor productivity (Bernard and Jensen, 1999, Aw, Chung and Roberts, 2000, Pavcnik, 2002)⁷ or labor productivity (Bernard and Wagner, 2001). I contribute to the literature by considering environment-related productivity, which may play an increasingly significant role as more attention is paid to global climate change and the increase in energy prices.

The related literature suffers from a number of caveats. CDK highlights the “absence of clear theoretical foundations to guide the empirical analysis” in this field, and the authors emphasize the usefulness of the Ricardian comparative advantage framework to discuss the relationship between trade and the environment. Moreover, technology to improve environmental externalities is often ignored in the literature that studies the relationship between productivity and trade (Carraro, Fay and Galeotti, 2014). In an industry-level analysis that focuses on environment-related efficiency, CDK provides a theoretical model of Ricardian comparative advantage based on a micro-economic theoretical foundation. The model theorizes the effect of intra-industry heterogeneity in labor productivity on export performance and predicts that increases in relative productivity lead to better export performance. CDK also empirically test the prediction of their model. The dependent variable in the empirical model is the log of export, which is disaggregated by exporting and importing countries and differenced across exporters and industries. The productivity in CDK is a relative price using producer price indices⁸. I base this analysis on the CDK model by moving the focus from labor productivity to environment-related productivity, which is measured by energy usage and pollution emissions per unit of production. The roles of energy and environmental quality in economic activity, more specifically in trade, are further analyzed based on the CDK model in the next section.

3. The empirical model and the data

3.1 Models

This empirical analysis is based on the structure of the theoretical model built by CDK. CDK's

⁶ Other facts can be summarized as follows: (i) large firms expand their scale and small firms exit the market when a trade policy increases export volume, and (ii) free trade of a good leads to increased productivity in the industry.

⁷ Aw, Chung and Roberts (2000) measured productivity using a multilateral index, and Pavcnik (2002) used the Olley-Pakes method.

⁸ Costinot and Komunjer (2008), the previous version of CDK, use production per unit of labor as productivity.

theoretical model⁹ leads to empirical estimation using the following structural model.

$$\log \tilde{x}_{ijt}^k = \delta_{ij} + \delta_j^k + \tau_t + \theta \log e_{it}^k + \epsilon_{ijt}^k \quad (3.1)$$

$$i = 1, \dots, \text{Exporters}; j = 1, \dots, \text{Importers}; k = 1, \dots, \text{Industries}; t = 1, \dots, \text{Time}$$

where \tilde{x}_{ijt}^k is an export from country i to country j in industry k at time t ; δ_{ij} and δ_j^k are dummy variables to indicate the i th exporter- j th importer and k th industry in j th importer; τ_t is a year-specific dummy variable; and ϵ_{ijt}^k is an error term. \tilde{x}_{ijt}^k is the corrected export by import penetration ratio (IPR), which is defined as $1 - x_{iit}^k / (\sum_{i'=1}^I x_{i'it}^k)$. It is a fixed effect, and it captures any attribution between export country i and import country j whose examples are provided by trade barriers. The other fixed effect, δ_j^k , captures any attribution of industry k in import country j , and its example is provided by policy barriers and/or preferences in industry k across import country j .

This estimation model replaces the labor productivity in CDK's model with environment-related efficiency. CDK assumes labor's mobility across industries and immobility across countries. Similarly, I assume the same for the mobility of energy sources. Although my focus is not to defend this assumption, I see patterns of energy source mobility that support the implications of the assumption. For example, fossil fuel trade is restrained because of the destination clause, which prohibits a buyer from reselling crude oil and natural gas. Moreover, not all energy commodities are allowed to trade internationally.

In equation (3.1), e_{it}^k expresses the efficiency in country i . The efficiencies that I focus on are energy efficiency and pollution efficiency, which are energy consumption per production, carbon dioxide (CO₂) emissions per production, sulfur oxide (SO_x) emissions per production and nitrogen oxide (NO_x) emissions per production in country i in industry k . According to the estimate model, I empirically analyze a parameter θ , which is an elasticity of an export with respect to the efficiencies, for exporting any good k from country i to country j .

Improving environment-related efficiency depends on technological progress. Compared with CDK's model, my model differs in that I consider the time effect as an underlying variable for progress. I, however, face difficulty in estimating my model because I need to estimate a fixed-effect model that contains the two individual effects as well as the time effect using panel data that consists of three factors¹⁰. Moreover, for the variables of individual effects, δ_{ij} , δ_j^k and τ_t , in total, there are more than sixteen thousand dummy variables.

The estimation model in CDK corresponds to their theoretical framework, and the estimated parameters are structural. Hence, the time effect in this estimation model is not based on their theoretical consideration but captures the difference between time units, which is influenced by economic repercussions in response to local and global events.

Additionally, I consider a variation of model (3.1) in order to capture the individual effects,

⁹ See theorem 1 in CDK.

¹⁰ The export in the model contains three factors: exporter i exports a good k to country j in a year.

which is expressed,

$$\log \tilde{x}_{ijt}^k = v_{ij}^k + \tau_t + \zeta \log e_{it}^k + \epsilon_{ijt}^k \quad (3.2)$$

where v_{ij}^k represents one individual effect which means that an exporter i exports a good k , to a country j . The individual effect in the model captures the circumstance of a trade between exporter i and importer j in industry k and can be regarded as both δ_{ij} and δ_j^k in model (3.1). Model (3.2) can be estimated with regular panel data.

I consider two different models, one with the measures of environment-related efficiencies as the explanatory variable and the other with an additional labor-productivity-related variable. I provide the results of this alternative model in Appendix. A.

3.2 Data

This analysis uses two separate datasets, data on trade flow and data on the measures of environment-related efficiencies. Both required datasets can be acquired from the WIOD, which consists of four parts: the world input output (IO) table, the national IO table, and socioeconomic and environmental satellite accounts. The world IO and the national IO are available for the period of 1995 to 2011, but the environmental-efficiency-related data are only available up to 2009; therefore, I limit this analysis to the period of 1995 to 2009.

Trade flow data are derived from the world IO table. I use the bilateral export of final private consumption as the dependent variable. The bilateral exports are from 22 exporting countries i to each of 41 importing countries j for each of 20 industries k , which are equivalent to \tilde{x}_{ijt}^k in this empirical models. My selections of export countries i and industries k are listed in Table 3-1. Following CDK, I correct the export data using IPR.

I measure the efficiencies across countries and industries using the world IO table and environmental accounts. The environmental accounts include data on energy use and CO₂, SO_x, and NO_x emissions at the industry level. From energy use and the emissions data, I calculate the industry-level energy efficiency and pollution efficiency. These efficiencies are measured by the ratio of the value of energy use or emissions to total production by industry. An additional efficiency measure, namely, labor productivity, is used in this estimation, and I also use the variables from socioeconomic accounts. Labor productivity is calculated as the ratio of the labor force to the total output.

Table 3-1 lists the countries and the industries that are included in the analysis. Table 3-2 provides the descriptive statistics calculated across countries and industries. I code the absence of trades in a country and an industry as 0 in my analysis. Figure 3-1 shows the relationship between the exports and the environment-related efficiency in 40 countries. The figure also indicates a positive correlation between the exports and the four efficiencies.

<Table 3-1>

<Table 3-2>

<Figure 3-1>

4. Results

4.1 The impact of environment-related efficiency on export performance

I estimate the effect of environment-related efficiency on the trade patterns across countries and industries. I focus on the parameters of θ and ζ , which represent an elasticity of export with respect to the efficiencies.

Table 3-3 reports the estimates of θ in model (3.1). Columns (1) to (4) show the results using bilateral export data without adjustment by IPR, and the remaining columns show the results using the adjusted export data. According to the theoretical implication in CDK, when I use the adjusted bilateral export data, I expect the negative estimates to be negative, and I also expect smaller estimates compared with when I use unadjusted data. From the results, *ceteris paribus*, a one percent improvement in the efficiencies leads to an increase in exports in the range of approximately 0.025 to 3.83, and the estimates with adjusted bilateral exports are found to be slightly smaller than the estimates without the adjustment. The difference in magnitude in the treatments for the exports agrees with the finding of CDK.

There is a correlation between explanatory variables and error terms when I consider the relationship between more disaggregated firm- or plant-level exports and environment-related efficiency. The correlation causes simultaneous equation and attenuation biases, which are caused by a measurement error in the efficiencies and leads to the underestimation of the parameters. Although the simultaneous bias is a potential concern for a relationship between unobserved firms' internal productivity and factor endowments¹¹, my main question is the impacts of environment-related efficiency, not those of total factor productivity.

To take the bias into account, model (3.1) is estimated using instrument variables for the endogenous regressor, $\log e_{it}^k$. A government generally makes different decisions from households and firms and intervenes to improve efficiencies. I use the government expenditures, taxes and subsidies in the WIOD as the instrument variables. Columns (9) to (12) in Table 3-3 show the instrument variable (IV) estimate of θ . The impacts of energy use, CO₂ emissions, and NOx emissions are negative and statistically significant, but the θ of SOx emissions is opposite in sign. The magnitude of θ from the IV estimation is larger than that of the estimates from OLS estimation. This difference is likely caused by the previously discussed attenuation bias.

<Table 3-3>

Table 3-4 reports the results of model (3.2). Columns (1) to (4) show the results using fixed-effect models. The impacts of energy efficiency and pollution efficiency, ζ , are larger compared with those in model (3.1). Considering the endogeneity of the regressor, I estimate model (3.2) using a dynamic GMM. When I compare columns (1) to (4) and (5) to (8), the

¹¹ Olley and Pakes measure productivity using a proxy for unobserved plant-level information. Pavcnik shows that the improved productivity caused by firms' exits because of cutoff tariffs leads to more exporting using the Olley-Pakes method.

magnitude of ζ with the dynamic GMM is found to be larger. Both models (3.1) and (3.2) show the expected impacts of the efficiencies.

<Table 3-4>

4.2 Estimating the impact in each industry

The results of the environment-related efficiency show that the industries with higher efficiency tend to export more, but the estimated models do not take the differences in industrial efficiency into account. I further investigate the impacts of environment-related efficiency by industry because energy consumption and emissions depend partly on industrial characteristics. In the context of the environmental economics literature, the industrial characteristics of energy use are important issue for environmental regulations. Pollution-intensive industries may face high abatement costs and are more likely to be influenced by economic regulatory instruments, such as environment taxes and other restrictions. Ederington, Levinson and Minier (2005) observe that the estimated average effect of abatement costs on all industries will lead to underestimation for some industries. Thus, given that I use the data of 20 different industries in this study, it is important to consider whether the impacts of environment-related efficiency differ by industry.

There are a number of reasons for which I expect industrial characteristics to affect relative energy efficiency. First, energy can be used as either a source of power or heat or as raw material. For example, petroleum can be used as a fuel in the form of gasoline, but it can also be used as a raw material in the petroleum chemical industry to produce vinyl and plastic. Even if both types of usage count as energy consumption, when the energy source is used as raw material, it is less likely to actually produce emissions.

Second, depending on the technology choice, the energy source and emission levels may vary. For example, the blast furnace is a conventional technology used in the iron and steel sectors. Furnaces use coke, but furnaces have been replaced by different technologies, such as direct-reduced iron, which uses natural gas. According to report by the International Energy Agency (2010a), direct-reduced iron technology allows natural gas to replace coke as the main energy source in the iron and steel industry.

Third, the industries in energy-intensive sectors are more likely to be energy efficient because they utilize recovery technology to use the energy that is the by-product of their production processes as their power and heat sources. For example, coke oven gas in the steel and iron sector and refinery gas in the petroleum sector are generated from their production processes and are used as energy sources in the related production processes.

For a number of reasons, including the three points mentioned above, industry-specific technology and production processes influence environment-related efficiency. Thus, it is important to consider the industry-specific impact when I analyze the relationship between export performance and environment-related efficiency.

Additionally, I investigate the effect of environment-related efficiency by industry in each country. When I look at the same industry across different countries, I expect the impact of that

industry's environment-related efficiency to be roughly the same because the elemental technology in each industry is essentially the same across countries. Although I expect relatively constant results across countries by industry, there may be cases in which the effect of environment-related efficiency in a particular industry may differ visibly by country. I may observe such differences owing to variations in energy access because countries vary in their endowment of natural resources. A country in which energy resource endowment is scarce may use energy more efficiently, and a country with a relatively rich endowment of less pollution-intensive energy has relatively low abatement costs.

Another factor that can cause within-industry differences across countries is country-specific regulations and subsidies. The International Energy Agency (2010b) reports that the subsidies related to fossil fuel consumption amounted to roughly 312 billion dollars in 2009. Governments use energy subsidies to bring down the production costs in the energy sector. With heavy subsidies to the energy industry, other industries can benefit from lower energy prices. This may lead to reduced incentives to be energy efficient. Environmental regulations can also influence an industry's relative energy efficiency. The stringency of environmental regulations is different across countries, and some industries are legally allowed to opt out of the regulations to promote international competition.

In order to consider the environment-related efficiency by industry in detail, I use two separate models: one with an interaction variable between environment-related efficiency and industry dummies and the other with the additional triple interaction of environment-related efficiency, industry dummies and country dummies.

$$\log \tilde{x}_{ijt}^k = \delta_{ij} + \delta_j^k + \tau_t + \theta \log e_{it}^k + \delta_i + \delta_j + \delta^k + \tilde{\theta}_1 \cdot \delta^k \cdot \log e_i^k + \epsilon_{ijt}^k \quad (4.1)$$

where δ_i , δ_j and δ^k are dummy variables in the exporting country, importing country, and industry, respectively. This model is based on model (3.1), and I add individual effects to it. An estimate of $\theta + \tilde{\theta}_1$ captures the marginal contribution of efficiency to export performance across industry, and I regard it as a measurement of the impact of each industry.

θ is one of the important parameters in CDK and measures intra-industry heterogeneity. In CDK, θ is assumed to be constant across exporting countries and across industries. In contrast to CDK, I lift the assumption of constant θ in this estimation models (4.1) and I let θ vary across industries. By allowing θ to vary, there may be a concern that the estimation model calculates absolute rather than comparative advantage. However, a closer look at the model indicates that it can be used to calculate comparative advantage.

From my definition of environment-related efficiency, the ratio of the efficiency in exporting country \tilde{i} and i , $e_{\tilde{i},t}^k / e_{i,t}^k$, shows the extent to which exporting country \tilde{i} holds an absolute advantage in efficiency related to country \tilde{i} in industry k . From the results of CDK, the relationship between export performance and the absolute advantage of the efficiency in industry k is expressed as

$$\log\left(\frac{x_{ijt}^k}{x_{i'jt}^k}\right) = \vartheta \log\left(\frac{e_{it}^k}{e_{i't}^k}\right) - \vartheta \log\left(\frac{d_{ijt}^k}{d_{i'j}^k}\right) \quad (4.2)$$

where the ratio of $e_{it}^k/e_{i't}^k$ expresses the degree of the absolute advantage of the efficiency. The relationship between export performance and the efficiency in (4.2) is for any importer j and any pair of exporters i , and i' but for the identical industry k . Hence, ϑ is an industry-specific impact of efficiency on export performance. According to classical trade theory, trade patterns do not vary as long as the comparative advantage of the efficiency for any importer, any pair of exporters, and any pair of industries does not change even if the absolute advantage of the efficiency for any importer or pair of exporters in the same industry changes. Therefore, regardless of the results from model (4.1), the comparative advantage confirmed by the results of model (3.1) stands on its own. Thus, the estimated parameters from model (4.1) capture the impacts of industrial characteristics on export performance.

An estimation model to investigate the impact across countries is written as

$$\begin{aligned} \log \tilde{x}_{ijt}^k = & \delta_{ij} + \delta_j^k + \tau_t + \theta \log e_{it}^k + \delta_i + \delta_j + \delta^k + \tilde{\theta}_1 \log e_{it}^k \cdot \delta^k \\ & + \tilde{\theta}_2 \cdot \delta_i \cdot \delta^k \cdot \log e_{it}^k + \epsilon_{ijt}^k \end{aligned} \quad (4.3)$$

where δ_i , δ_j and δ^k are the same dummy variables as in model (4.1). $\tilde{\theta}_2$ in model (4.3) captures the industry-specific impact of environment-related efficiency on trade performance across countries. Estimation model (4.2) is helpful to consider the industry-specific impact from model (4.2).

Table 3-5 shows the industrial rank order of a marginal impact of environment-related efficiency. This order is based on the estimated $\theta + \tilde{\theta}_1$ in model (4.1) using the IV method. I am interested in the difference in impact between industries, and I show the industries in descending order of impact because the estimation results cannot easily be read. Table 3-6 shows the industry-specific impact of energy efficiency on export performance across countries. The number in the table is $\theta + \tilde{\theta}_1 + \tilde{\theta}_2$ in model (4.3) and is equal to the marginal impacts in each industry, which are divided into impact across countries. The sign of each marginal impact can be positive or negative, and a negative value indicates that more energy-efficient industries export more. Figure 2 describes the number of negative values of the marginal effects in environment-related efficiency.

The results of industrial impacts in Table 3-5 and Figure 3-2 have three features: 1) the top-ranked industries in Table 3-5 have more negative impact values across countries, 2) the industries that rank at the bottom have fewer negative values, and 3) the industries that are inversely related in ranking order have some negative impacts. The first and the second features are in line with expectations, but the third feature implies that country-specific factors influence particular industries.

From Table 3-5 and Figure 3-2, I find that the electric equipment and transport equipment industries are placed near the top of the ranking for all efficiency measures, and this result is robust when I look at the impact of environment-related efficiency on export performance by

industry in each country. One possible explanation for why environment-related efficiency has a significant positive impact on the export performance of these industries is that these industries are highly competitive in the international market. Hence, a small difference in energy efficiency affects their performance. In other words, competition leads to high opportunity costs for not being energy efficient. This result also shows that the food industry ranks in efficiency impact. Although the food industry is less susceptible to international competition compared with electric and transportation, the impact of efficiency on export performance may be strong because energy costs are a dominant cost factor and energy efficiency is key for business management in the industry (American Gas Funding, 2005, U.S. Environmental Protection Agency, 2007).

The industries that rank low in terms of impact of efficiency belong to energy-intensive sectors, such as coke and fuel, basic metals, and non-metals; these industries rank near the bottom in all efficiency measures. Moreover, when I consider these industry-specific efficiency impacts by country, I observe that the positive impacts of industry-specific environment-related efficiency on export performance are consistent across countries for the top-ranked industries. However, for the low-ranked industries, the industry-specific impacts vary across countries; they are sometimes positive and sometimes negative depending on the country. The reason I observe such variation in the impacts of low-ranked industries may be that these industries are what I often call the heavy industries, which heavily depend on natural resources; thus the efficiency impacts depend on country-specific characteristics of energy source endowment.

<Table 3-5>

<Figure 3-2>

<Table 3-6>

4.3 Discussion of the empirical results

I find that environment-related efficiency explains the existence of comparative advantage in export performance. This implies that improved efficiency increases export performance. This result leads us to the next question: How do I increase environment-related efficiency given that increasing export performance is an important economic concern for countries? Although there are multiple ways to improve environment-related efficiency, I discuss two possible mechanisms.

One is improving the technology and labor skills that would contribute to increased energy efficiency in production processes. This could be accomplished through either government regulations and subsidies or voluntary efforts by firms themselves. Many countries address energy efficiency and climate change policy (see the IEA 'Policy and Measure Database' ¹²), and they structure their regulations and economic policies to meet certain goals and standards. Moreover, some empirical works show that environmental regulations enforced by governments improve firm performance (Rexhäuser and Rammer, 2014, Lanoie et al., 2011).

¹² It is available at <http://www.iea.org/policiesandmeasures/>.

The migration of industries can achieve increases in average energy efficiencies in both developed and developing countries according to the assumption of the pollution haven hypothesis. The reason is that efficient industries migrate out of countries to avoid stringent environment regulations, and the average efficiency increases in the home country, where the industries with high environment-related efficiency can comply with more strict regulations. In contrast, however, those industries that migrated to the countries with relatively softer environmental regulations could have higher energy efficiency compared with the existing industries in the host countries. Therefore, the average efficiency can be increased in both countries.

My analysis does not provide definite support for which mechanisms or what combinations of these mechanisms actually increase energy efficiency, but this results may provide some hints regarding what mechanisms lead to greater environment-related efficiencies. The results indicate that the positive impact of energy efficiency is larger in relatively mobile industries, such as electric and transport equipment, whereas the efficiency impact on export performance is low in relatively heavy industries. The top large firms in electric equipment and transport equipment, such as General Electrics, Samsung, Toyota and the other major companies, have built plants outside of their home countries. However, heavy industry by definition is energy-source-intensive and depends heavily on each country's specific endowment of natural resources. Therefore, the firms in heavy industry are less mobile given that migration is limited by the availability of access to energy sources. This result may imply that migration is relevant when I consider the relationship between energy efficiency and export performance.

5. Concluding Remarks

I analyze the impact of energy and pollution efficiencies on export performance based on the recent trade theory by Costinot, Donaldson and Komunjer (2012) using comparative industry-level data. The empirical results indicate that industries with higher energy and emission efficiency tend to export more. This estimation shows that 1 percent decreases in energy consumption, CO₂ emissions, and NO_x emissions per unit of production lead to 1.6, 3.8, and 2.7 percent increases in exports, respectively.

I further investigate the impact of industry-specific efficiency on export performance as well as the effect of industry-specific efficiency by country. This extension is important because the effects of environment-related efficiency vary depending on industry characteristics, such as different energy source usage and production technologies. This results indicate that the less energy-intensive industries tend to show a greater positive efficiency impact on export performance compared with the heavy industries, which tend to depend more on country-specific resource endowment.

Given the indication that improving environment-related efficiency leads to increased export performance, it is in industries' as well as governments' interest to think about how to actually increase energy efficiency. Although there may be multiple ways to achieve this increase, I briefly

highlight two possible mechanisms.

One is by developing and applying related technology that leads to increased energy efficiency in production. This could be accomplished through either government regulations and subsidies or voluntary efforts by firms themselves. Secondly, average energy efficiencies can be increased by the migration of industries. According to the pollution haven hypothesis, industries with low energy efficiency migrate out of countries with more stringent regulations, and this migration increases the average energy efficiency those countries. In contrast, those industries that migrate to developing countries with relatively more lax environmental regulations could have higher energy efficiency compared with the existing industries in the host countries. Therefore, in both countries, average energy efficiencies can be increased through industry migration. As I discussed above, my results appear to imply that industry migration may be important when I consider the effect of energy efficiency on export performance. As for future research, it would be important to empirically analyze whether regulations and/or industry migration actually contribute to increasing energy efficiencies and thus lead to improved export performance.

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Appendix

A. CONSIDERATION OF LABOR PRODUCTIVITY

I consider a model with not only the environment-related efficiency variable but also the labor-productivity-related variable, which is considered to be influential in export performance. My attempt is to add labor productivity X_{it}^k into model (3.1), and the resulting estimation model

is expressed as

$$\log \tilde{x}_{ijt}^k = \delta_{ij} + \delta_j^k + \tau_t + \theta \log e_{it}^k + \xi \log X_{it}^k + \epsilon_{ijt}^k \quad (\text{A.1})$$

$$i = 1, \dots, \text{Exporters}; j = 1, \dots, \text{Importers}; k = 1, \dots, \text{Industries}; t = 1, \dots, \text{Time}$$

where the variables except labor productivity are the same as those for model (3.1).

Table A 1 reports the estimate θ in this model, on which I focus as the impact of environment-related efficiency on export performance. The estimates of θ and ξ are expected to carry the same negative sign as in previous two models in this paper.

Compared with the estimated parameters in Table 3-3, there is little parameter change from the additional regressor. However, there are also different magnitudes of the estimated coefficient between OLS and IV in the table; the magnitudes using IV are greater than those from OLS. This casus of parameters is observed in CDK, and the authors observed that the magnitude of θ by IV is thought to be derived from an attenuation bias that is caused by a measurement error in efficiency. It is likely that efficiency as an exogenous variable leads to a bias that increases the magnitude.

Figures

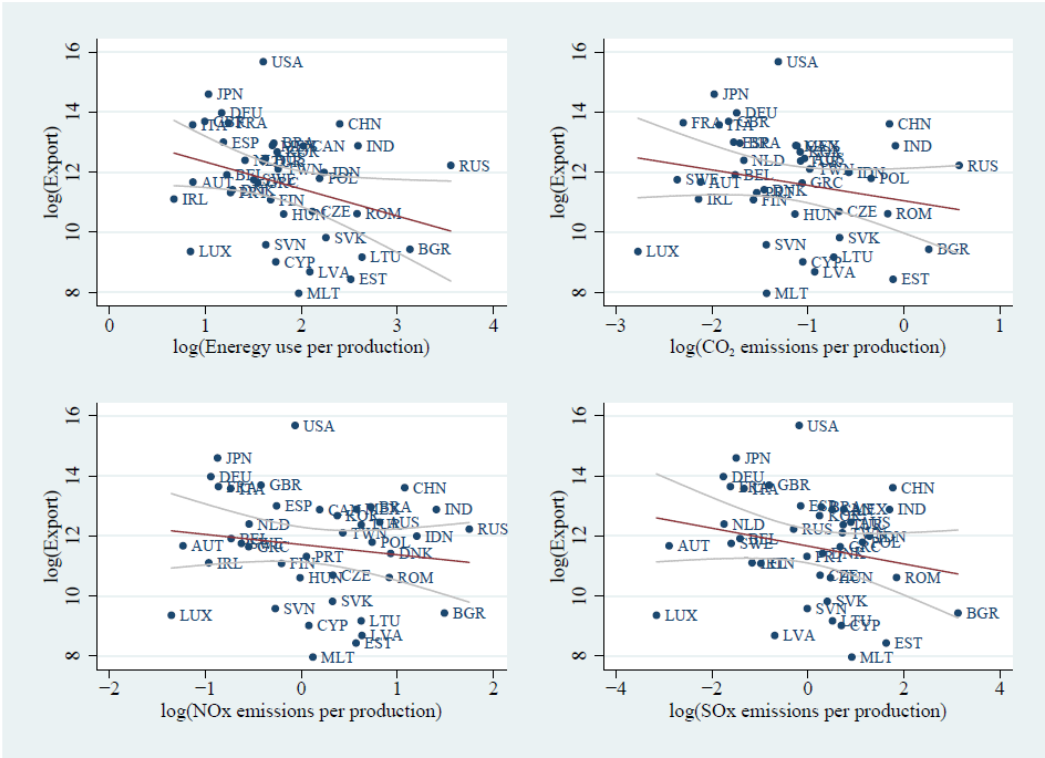


Figure 3-1 Export and the energy use per production and pollution emissions per production

Note: This plot depicts a relationship between the export and environment-related efficiency, which is measured by energy consumption and pollution emissions per unit of production in 40 countries. Each data point is an annual average amount of each country for all industries.

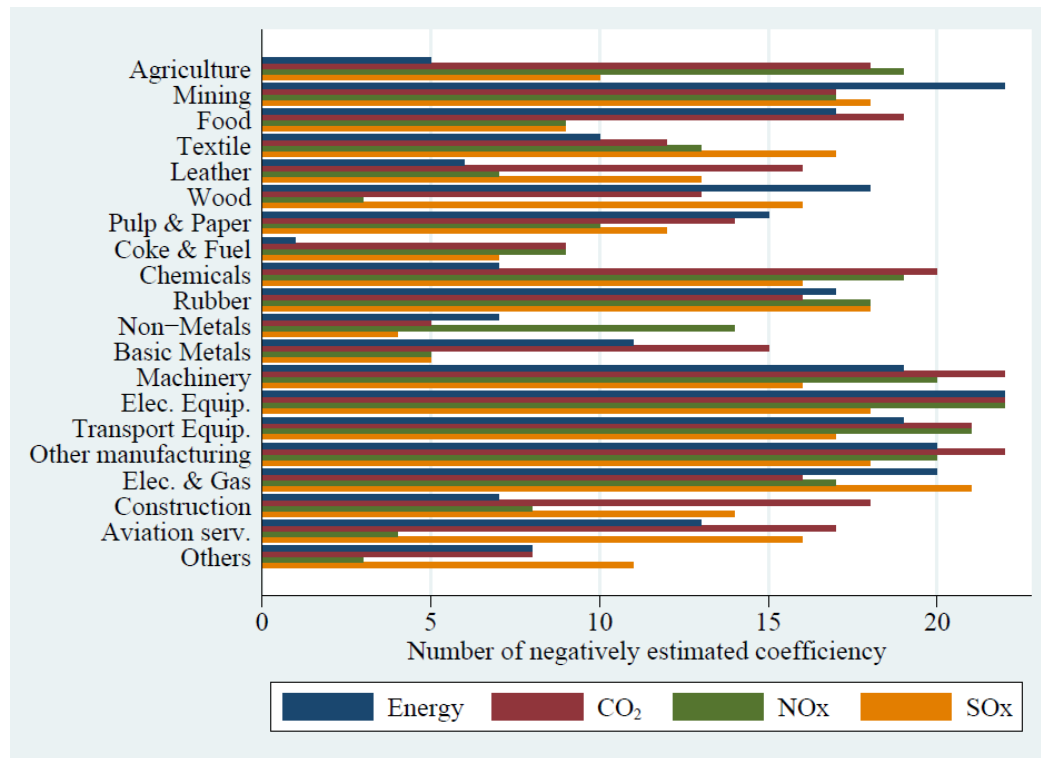


Figure 3-2 Number of negative impacts of the environment-related efficiency across country

Note: Negative impacts of the environment-related efficiency is equal to $\theta + \tilde{\theta}_1 + \tilde{\theta}_2$ in model (4.2) which is estimated as negative sign.

Tables

Table 3-1 Data source and description of data set.

Source	World Input Output Database http://www.wiod.org		
Data type	World Input-Output Tables released November 2013 National Input-Output Tables released November 2013 Socio Economic Accounts released February 2012 Environmental Accounts released March 2012		
Period	From 1995 to 2009		
Country	Exporter (22)	Australia, Belgium, Brazil, Canada, China, Germany, Spain, France, United Kingdom, Indonesia, India Italy, Japan, Korea, Mexico, Netherlands, Poland, Russia, Sweden, Turkey, Taiwan, and United States	
	Importer (41)	Exporters and Austria, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Ireland Lithuania, Luxembourg, Latvia, Malta, Portugal, Romania, Slovak Republic, Slovenia, and Rest of the World	
Industry (20)			
Sector	Description	Sector	Description
Agriculture	Agriculture, Hunting, Forestry and Fishing	Non-Metals	Other Non-Metallic Mineral
Mining	Mining and Quarrying	Basic Metals	Basic Metals and Fabricated Metal
Food	Food, Beverages and Tobacco	Machinery	Machinery, Nec
Textile	Textiles and Textile Products	Elec. Equip.	Electrical and Optical Equipment
Leather	Leather, Leather and Footwear	Transport Equip.	Transport Equipment
Wood	Wood and Products of Wood and Cork	Other manufacturing	Manufacturing, Nec; Recycling
Pulp & Paper	Pulp, Paper , Printing and Publishing	Elec. & Gas	Electricity, Gas and Water Supply
Coke & Fuel	Coke, Refined Petroleum and Nuclear Fuel	Construction	Construction
Chemicals	Chemicals and Chemical Products	Aviation serv.	Air Transport
Rubber	Rubber and Plastics	Others	Service sectors not elsewhere classified

Table 3-2 Summary statistics.

	Dimension	Observation (excl. missing obs.)	Mean	Maximum	Minimum	Standard deviation
Export	Million of U.S.\$	270,601	981	6,287,692	0.0	6,287,692
Energy use per prod.	Million of joule per U.S.\$	6,599	14.87	913.3	0.076155	913.25
CO ₂ per prod.	Kilogram per \$	6,584	0.90	47.8	0.000867	47.80
NO _x per prod.	Tonnes per million \$	6,584	2.76	172.7	0.001824	172.73
SO _x per prod.	Tonnes per million \$	6,584	3.73	376.8	0.000065	376.77
Labor per prod.	Person per \$	6,599	0.040	2.06	0.000225	2.06
Capital stock per prod.	Dimensionless (million \$ per million \$)	6,280	1.06	12.0	0.007652	12.02

Table 3-3 Results of model (3.1).

Regressand	log (export of final goods)				log (corrected export of final goods)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
log (energy use per production)	-0.126*** (0.00746)				-0.125*** (0.00748)				-1.605*** (0.0491)			
log (CO ₂ emissions from fuel combustion per production)		-0.138*** (0.00722)				-0.138*** (0.00724)				-3.825*** (0.0718)		
log (NO _x emissions per production)			-0.109*** (0.00626)				-0.109*** (0.00627)				-2.668*** (0.0573)	
log (SO _x emissions per production)				-0.0248*** (0.00390)				-0.0234*** (0.00391)				4.269*** (0.214)
Individual effects												
» Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
» Export country x Import country	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
» Import country x Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Estimation Method	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	2SLS	2SLS	2SLS	2SLS
Observations	258437	257837	257837	257837	258318	257718	257718	257718	150188	149668	149668	149668
AIC	1033510	1028904	1029007	1029340	1034534	1031606	1031709	1032052				
R-square: overall	0.780	0.781	0.780	0.780	0.779	0.779	0.779	0.779				

Note: I estimate the model (3.1) using data from 22 counties 20 industries from 1995 to 2009, which are listed in the Table 3-1. Corrected export of goods is adjusted using IPR. Production in the regressors is output that is evaluated at the price in 1995. Year is time dummy. Export country x Import country is fixed effect of export and import, and Import country x Industry is fixed effect of import and industry. *** represents statistical significance at 1 percent level. A test for the regressor with a correlation of error term or a measurement error is carried out, so the hypothesis of exogeneity of environment-related efficiency in the model is rejected. A test of over-identification is carried out to check the adequacy of instrument variables, which are capital stock, government expenditure, indirect tax and subsidy, and dummy variables. The hypothesis of over-identification is not rejected. It is likely that at least some of these instrument variables may not be exogenous.

Table 3-4 GMM estimation results.

Regressand	log (corrected export of final goods)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log (corrected export of final goods) _{<i>t-1</i>}					0.682*** (0.0274)	0.665*** (0.0259)	0.631*** (0.0285)	0.640*** (0.0286)
log (energy use per production)	-0.332*** (-48.16)				-0.358 (0.263)			
log (CO ₂ emissions from fuel combustion per production)		-0.315*** (-48.37)				-0.342 (0.334)		
log (NO _x emissions per production)			-0.282*** (-51.88)				-0.414** (0.136)	
log (SO _x emissions per production)				-0.158*** (-47.15)				-0.124 (0.138)
Individual effects								
» Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
» Export x Import x Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Estimation Method	LSE	LSE	LSE	LSE	GMM	GMM	GMM	GMM
Observations	258318	257718	257718	257718	152962	152442	152442	152442
R-square: overall	0.092	0.074	0.113	0.066				

Note: I estimate the model (3.2) using data from 22 counties 20 industries from 1995 to 2009, which are listed in the Table 3-1. Corrected export of goods is adjusted using IPR. Production in the regressors is output that is evaluated at the price in 1995. Year is time dummy. Export country x Import country is fixed effect of export and import, and Import country x Industry is fixed effect of import and industry. *** represents to be statistically significantly different from zero at the one percent level. The tests for the regressor with a correlation of error term or a measurement error are carried out, and the hypothesis of exogeneity of the environment-related efficiency in the model is rejected. The specification test is carried out to check the adequacy of an instrument variable (government expenditure in model (5) to (8)). In the Arellano-Bond test for autocorrelation, model (5) and (6) do not reject the null hypothesis in AR(1) but reject it in AR(2), but in the J test of Hansen, model (5) and (6) reject the null hypothesis. The results of the tests indicate that the models (7) and (8) are not adequately explained.

Table 3-5 Industry ranking of environment-related efficiency impact on export performance.

Rank	Environment related efficiency			
	Energy	CO ₂	NO _x	SO _x
1	Food	Food	Food	Elec. & Gas
2	Transport Equip.	Pulp & Paper	Construction	Coke & Fuel
3	Chemicals	Transport Equip.	Transport Equip.	Food
4	Elec. Equip.	Chemicals	Coke & Fuel	Chemicals
5	Pulp & Paper	Elec. Equip.	Chemicals	Elec. Equip.
6	Other manufacturing	Construction	Machinery	Transport Equip.
7	Machinery	Coke & Fuel	Elec. Equip.	Aviation serv.
8	Leather	Machinery	Pulp & Paper	Construction
9	Agriculture	Leather	Elec. & Gas	Machinery
10	Textile	Aviation serv.	Other manufacturing	Pulp & Paper
11	Construction	Elec. & Gas	Mining	Other manufacturing
12	Non-Metals	Other manufacturing	Basic Metals	Basic Metals
13	Basic Metals	Basic Metals	Leather	Rubber
14	Elec. & Gas	Rubber	Rubber [†]	Mining
15	Aviation serv.	Agriculture	Non-Metals	Others
16	Wood	Mining	Aviation serv.	Non-Metals
17	Coke & Fuel	Textile	Wood	Wood
18	Rubber	Wood	Textile	Leather
19	Mining	Non-Metals	Agriculture	Textile
20	Others	Others	Others	Agriculture

Note: The ranking is based on the model (4.1).[†] Rubber in NO_x is same rank as Leather.

Table 3-6 Industry specific impact of energy efficiency on export performance by country.

Exporting country	Agriculture	Mining	Food	Textile	Leather	Wood	Pulp & Paper	Coke & Fuel	Chemicals	Rubber	Non-Metals	Basic Metals	Machinery	Elec. Equip.	Transport Equip.	Other manufacturing	Elec. & Gas	Construction	Aviation serv.	Others
Australia	0.94 (0.54)	-0.35 (-0.39)	0.79 (1.16)	0.03 (-0.13)	1.03 (0.29)	0.21 (-0.07)	0.24 (0.26)	0.24 (-0.21)	0.21 (-0.12)	0.20 (0.58)	-0.25 (-0.10)	0.22 (0.22)	-0.63 (-0.57)	-0.57 (-0.27)	0.20 (0.12)	-0.13 (-0.05)	-0.24 (-0.40)	0.30 (-1.63)	0.94 (0.43)	3.88 (3.38)
Belgium	1.71 (-0.39)	-1.51 (-1.51)	-0.12 (1.22)	-0.47 (-0.48)	0.90 (0.92)	-0.15 (-0.27)	-0.26 (-0.09)	1.53 (1.06)	0.35 (0.03)	0.33 (-0.18)	-0.11 (0.24)	0.55 (0.61)	0.89 (0.81)	-0.34 (-0.09)	-0.88 (-0.86)	-1.16 (-1.24)	0.04 (-0.18)	-0.67 (-2.21)	0.13 (-0.28)	1.68 (1.47)
Brazil	1.71 (0.95)	-0.47 (-0.49)	0.99 (0.96)	-1.26 (-1.42)	-7.12 (1.14)	-0.92 (-1.05)	-0.86 (-0.81)	0.47 (0.06)	-0.0 (-0.64)	-1.24 (-2.0)	-0.04 (0.19)	-0.03 (-0.10)	-1.26 (-0.54)	-1.13 (-0.48)	-1.29 (0.47)	1.17 (-1.59)	-0.31 (-1.65)	13.25 (-0.64)	-1.17 (-2.04)	-0.06 (-0.92)
Canada	1.71 (0.69)	-1.29 (0.75)	-0.70 (0.61)	0.36 (-0.70)	0.43 (-1.15)	-0.41 (-0.56)	-0.01 (0.11)	0.47 (0.09)	0.98 (-0.36)	-1.24 (-0.05)	0.16 (-0.51)	-0.03 (0.29)	-0.18 (0.04)	-5.37 (-1.58)	-1.29 (-0.81)	-3.69 (-0.06)	-0.31 (-0.02)	13.25 (-4.30)	-0.78 (-0.10)	1.07 (1.12)
China	1.71 (-1.05)	-1.29 (-0.36)	-0.70 (-1.33)	0.36 (-0.14)	0.43 (-0.50)	-0.41 (0.14)	-0.84 (-0.97)	0.47 (-0.57)	0.98 (-1.0)	-1.24 (-0.67)	0.16 (0.29)	-0.03 (0.03)	-0.18 (-1.13)	-5.37 (-1.04)	-1.29 (-0.92)	-3.69 (-0.64)	-0.31 (0.43)	13.25 (-0.80)	-0.78 (-1.79)	3.10 (-1.79)
Germany	-0.81 (-0.95)	-0.44 (-0.48)	-0.67 (0.32)	-0.18 (-0.19)	0.53 (-0.0)	-0.83 (-0.84)	0.70 (0.84)	0.45 (0.20)	0.23 (-0.06)	0.74 (0.09)	0.12 (0.49)	0.34 (0.43)	-0.65 (-0.78)	-1.19 (-0.82)	-2.35 (-2.11)	-0.06 (-0.02)	-0.13 (-0.25)	-0.02 (-2.78)	0.16 (-0.28)	1.12 (1.0)
Spain	1.51 (1.20)	-1.90 (-1.91)	-0.04 (0.59)	-0.32 (-0.45)	2.35 (0.98)	-0.61 (-0.87)	-0.30 (-0.34)	0.44 (0.06)	-0.06 (-0.41)	-0.36 (-0.91)	0.0 (0.23)	-0.23 (-0.28)	0.80 (0.84)	-0.27 (0.21)	-1.39 (-0.88)	0.25 (0.51)	-0.50 (-0.69)	0.77 (-0.36)	0.02 (-0.39)	-2.02 (-2.28)
France	1.92 (1.24)	-0.88 (-1.02)	1.34 (1.40)	0.70 (0.19)	7.62 (-0.09)	-0.41 (-1.08)	0.24 (0.02)	0.96 (0.44)	0.98 (-0.36)	-1.24 (-0.57)	0.16 (0.81)	0.21 (-0.01)	-0.18 (-0.03)	-1.68 (-0.95)	-1.70 (-1.04)	-2.22 (-1.38)	-0.16 (-0.37)	3.70 (3.44)	0.65 (0.06)	-0.75 (-1.67)
United Kingdom	-0.63 (-0.62)	-0.15 (-0.12)	-0.26 (0.78)	-0.26 (-0.10)	0.43 (-0.06)	-0.44 (-0.46)	0.81 (1.18)	0.52 (0.24)	0.31 (0.06)	-0.01 (-0.34)	0.06 (0.48)	0.09 (0.22)	-0.54 (-0.61)	-1.58 (-1.22)	-1.33 (-1.83)	-0.42 (-0.21)	-0.75 (-0.84)	2.65 (0.15)	-0.78 (-0.05)	0.02 (-0.74)
Indonesia	1.71 (0.44)	-1.29 (-1.11)	-0.70 (0.38)	0.36 (0.85)	0.43 (2.44)	-0.41 (1.72)	-0.84 (-0.15)	0.47 (0.23)	0.98 (-0.60)	-1.24 (0.81)	0.16 (0.66)	-0.03 (0.07)	-0.18 (-0.03)	-5.37 (1.58)	-1.29 (-1.34)	-3.69 (1.04)	-0.31 (-1.60)	13.25 (-0.66)	-0.78 (-0.10)	3.10 (0.48)
India	0.39 (0.66)	-0.58 (-0.47)	-0.44 (-0.15)	0.46 (0.59)	0.89 (0.78)	0.48 (0.54)	-0.85 (-0.66)	0.27 (0.06)	-0.26 (-0.33)	-0.04 (-0.37)	0.16 (0.26)	-1.84 (0.33)	-2.40 (-1.54)	-1.49 (-2.73)	-1.36 (-1.26)	-1.39 (-1.45)	-1.37 (-1.44)	-0.78 (0.06)	-1.80 (-1.10)	-1.83 (-1.83)
Italy	-0.44 (-0.58)	-1.29 (-1.27)	-2.23 (-0.96)	0.36 (0.30)	-2.42 (-1.41)	1.11 (0.54)	-0.84 (-0.71)	0.11 (-0.23)	-0.53 (-0.91)	-0.54 (-1.62)	-0.07 (0.25)	0.25 (0.31)	-0.18 (-0.56)	-0.15 (0.20)	0.73 (0.59)	-0.32 (-0.42)	-0.65 (-0.84)	1.68 (0.51)	-0.16 (-0.60)	3.10 (2.29)
Japan	1.71 (-1.67)	-1.29 (0.52)	-0.70 (-1.13)	0.36 (-0.63)	0.43 (0.42)	-0.41 (1.14)	-0.84 (0.43)	0.47 (0.67)	0.98 (0.75)	-1.24 (1.27)	0.16 (1.07)	-0.03 (1.80)	-0.18 (-4.58)	-5.37 (-4.37)	-1.29 (-5.18)	-3.69 (2.33)	-0.31 (-0.28)	13.25 (13.79)	-0.78 (0.61)	3.10 (5.27)
Korea	1.71 (-2.93)	-1.29 (-1.77)	-0.70 (-3.69)	0.36 (-0.14)	0.43 (-0.09)	-0.41 (-3.45)	-0.84 (-1.14)	0.47 (-0.46)	0.98 (-1.11)	-1.24 (-1.51)	0.16 (-0.52)	-0.03 (0.0)	-0.18 (-0.51)	-5.37 (-1.69)	-1.29 (0.23)	-3.69 (-0.65)	-0.31 (-0.86)	13.25 (-1.67)	-0.78 (-0.25)	0.77 (-0.60)
Mexico	0.41 (0.40)	-1.06 (-0.98)	-0.19 (0.56)	-1.11 (-1.0)	-1.32 (-1.91)	-0.74 (-0.73)	-0.74 (-0.53)	0.26 (0.01)	-0.29 (-0.48)	-0.15 (-0.39)	-0.08 (0.25)	0.17 (0.32)	-1.64 (-1.38)	-2.90 (-2.83)	-3.28 (-3.78)	-1.0 (-0.89)	-0.50 (-0.59)	-2.73 (-0.66)	-0.53 (-0.88)	0.98 (1.22)
Netherlands	0.98 (0.98)	-0.27 (-0.23)	1.35 (2.36)	-0.80 (-0.73)	0.02 (0.13)	-0.41 (-0.21)	0.82 (1.07)	0.66 (0.47)	0.35 (0.21)	0.54 (-0.07)	0.16 (0.67)	0.55 (0.73)	0.90 (0.98)	-0.54 (-0.41)	-0.10 (-0.18)	-1.35 (-2.21)	-0.24 (-0.36)	-0.80 (-2.04)	0.60 (0.22)	1.33 (1.49)
Poland	-0.33 (-0.48)	-0.20 (-0.24)	-0.79 (-0.44)	-0.64 (-0.75)	-0.46 (-0.84)	0.20 (0.08)	-0.72 (-0.69)	0.18 (-0.10)	-0.56 (-0.76)	-0.81 (-1.52)	0.11 (0.31)	-0.08 (-0.06)	-1.21 (-1.32)	-0.83 (-0.70)	-1.38 (-1.57)	-1.02 (-1.23)	-0.29 (-0.43)	-0.83 (-2.89)	-0.22 (-0.71)	-0.71 (-0.82)
Russia	0.38 (0.03)	-1.29 (0.05)	0.04 (-0.0)	-0.08 (-0.35)	-0.07 (-0.60)	-0.41 (-0.12)	-0.84 (0.07)	0.47 (1.15)	0.09 (-0.19)	-1.24 (-1.50)	0.16 (0.02)	-0.03 (-0.54)	-0.18 (0.43)	-5.37 (0.17)	0.04 (-0.57)	-0.32 (-0.75)	0.51 (0.28)	13.25 (1.51)	1.16 (0.53)	1.40 (1.08)
Sweden	-1.55 (-1.56)	-0.88 (-0.84)	-1.84 (-0.51)	-1.62 (-1.52)	-0.86 (-1.11)	-0.49 (-0.52)	0.22 (0.33)	0.64 (0.27)	0.38 (0.19)	0.30 (-0.0)	-0.30 (0.16)	0.04 (0.23)	-0.58 (-0.78)	-1.18 (-1.03)	-1.75 (-1.71)	-0.21 (0.04)	-0.30 (-0.38)	1.41 (-1.01)	0.06 (-0.38)	-0.53 (-0.14)
Turkey	1.54 (1.47)	-1.23 (-1.15)	-0.38 (0.49)	1.49 (1.55)	0.15 (-0.18)	-0.16 (-1.08)	-1.32 (-0.31)	-0.01 (-0.81)	-0.66 (-0.36)	-0.20 (-0.89)	0.51 (0.16)	0.02 (0.16)	-0.42 (-0.19)	-0.27 (-0.16)	-0.58 (-0.51)	-0.88 (-0.79)	-0.46 (-0.58)	-1.94 (-0.51)	-0.81 (-1.12)	-7.11 (-6.85)
Taiwan	1.71 (-2.10)	-1.29 (-1.24)	-0.70 (-3.22)	0.36 (-0.13)	0.43 (0.70)	-0.41 (-0.32)	0.12 (-0.21)	0.47 (-0.44)	0.98 (-0.65)	-1.24 (-1.81)	0.16 (0.20)	-0.03 (0.48)	-0.18 (-0.34)	-5.37 (-3.07)	-1.29 (0.07)	-3.69 (-1.75)	-0.31 (-0.81)	13.25 (4.75)	0.30 (-0.09)	-1.42 (-1.98)
United States	1.71 (0.49)	-1.29 (0.19)	-0.70 (0.28)	0.36 (-0.49)	0.43 (-1.51)	-0.41 (-0.55)	-0.84 (0.57)	0.47 (0.47)	0.98 (-0.07)	-1.24 (-0.63)	0.16 (-0.08)	-0.03 (0.10)	-0.18 (0.79)	-5.37 (-1.99)	-1.29 (-0.37)	-3.69 (-0.14)	-0.31 (-0.41)	13.25 (-0.48)	-0.78 (0.34)	3.10 (1.03)

Note: The upper values of each line are estimates using IV method, and lower values in parentheses are using OLS.

Table A 1 Two productivities using OLS and IV.

Regressand	log (corrected export of final goods)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log (energy use per production)	-0.140*** (0.00755)				-0.269*** (0.0477)			
log (CO ₂ emissions from fuel combustion per production)		-0.157*** (0.00741)				-3.941*** (0.0981)		
log (NO _x emissions per productic			-0.119*** (0.00630)				-1.971*** (0.0599)	
log (SO _x emissions per production)				-0.0286*** (0.00395)				5.093*** (0.156)
log (Labor per production)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual effects								
» Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
» Export country x Import cour	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
» Import country x Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Estimation Method	OLS	OLS	OLS	OLS	2SLS	2SLS	2SLS	2SLS
Observations	258318	257718	257718	257718	150188	149668	149668	149668
AIC	1034414.7	1031452.0	1031599.4	1031984.2				
R-square: overall	0.779	0.780	0.779	0.779				

Note: I estimate the model (3.1) using data from 20 industries in 22 countries from 1995 to 2009. The industries and countries are listed in the Table 3-1. Export of goods is adjusted using IPR. Production variable is an output that is evaluated at the price in 1995. Year is time dummy. I control the fixed effects of Export country x Import country and Import country x Industry. *** represents statistical significance at 1 percent level. A test for the regressor with a correlation of error term or a measurement error is carried out, so the hypothesis of exogeneity of environment-related efficiency in the model is rejected. A test of over-identification is carried out to check the adequacy of instrument variables, which are capital stock, government expenditure, indirect tax and subsidy, and dummy variables. The hypothesis of over-identification is not rejected. It is likely that at least some of these instrument variables may not be exogenous.

POSTSCRIPT TO THIS DISSERTATION

The dissertation explores the impact of energy and environmental policy on economic growth, domestic market, and international trade, which is broken into three essays. It is significant for the explorations to evaluate and predict the impact theoretically and empirically with the changing attitudes toward the mitigation policy. These different candidates in the dissertation, which are economic growth, domestic market in major countries, and international trade, is chosen among important topics to develop the sustainable society.

The chapter 1 investigates the energy and environmental policy by applying the optimal growth model to an environmental externality and a monopoly of renewable energy production. It is shown that levying a tax on the nonrenewable energy resources sector and awarding a subsidy for renewable energy use achieves the social optimum. The findings are as follows. A decentralized economy cannot attain the social optimum. Comparing the optimal conditions of the decentralized economy to the social planner's problem, we find that imposing an optimal tax on a nonrenewable energy producer coincides with both conditions. A lump sum transfer of the tax to a renewable energy use causes renewable energy to increase more than in the case without the tax. However, the simulation shows an inversion of magnitudes between the cases with and without taxes on renewable energy. This is because higher energy prices resulting from the scarcity of nonrenewable energy promotes the use of renewable energy. Other simulation results show the social losses under the damage functions. In our model, a social expense depends on the magnitude of social damage to the environment. A social loss in the 1% loss case costs \$1.8 trillion, and a social loss in the 5% loss case costs \$5.6 trillion. Moreover, it is shown that consumption and production are the lowest in the 5% loss case. This case has the highest amount of social damage. The monopoly of renewable energy production in the model is considered, which is one of externalities. The monopoly causes less supply of renewable energy, and constitutes barriers to the mitigation of climate change and to economic growth.

The chapter 2 considers the impact of climate regulation on the industries in major developing and developed countries following a methodology developed by Aldy and Pizer (2011). Reduction of fossil fuel is crucial in the face of increasing crude oil prices and global climate change. When a climate policy is enforced in one country, it is important to consider the policies that have been implemented by other major countries to reduce fossil fuel consumption. Aldy and Pizer (2011) provide a valid argument for such a case. This is different from many previous studies that focus on what happens when other countries have not introduced such policies. Comparing the analysis with their study, the scope from the only US to include forty major countries is expanded. The results show that some industries and countries have competitiveness effects, although the impacts are not particularly large. It is possible to substitute an imported product for a domestic good in some sectors to implement domestic regulation; however, protection from trade competition is less effective for particular industries. The analysis shows that some countries have a relatively high competitiveness effect, and the macro-economy of these countries would possibly be affected by domestic regulations. A global agreement would be helpful in buffering the reduction in production for these countries.

The chapter 3 investigates the effect of comparative advantage in terms of environment-related efficiency on export performance. The implication from the recent theoretical model in international trade suggests that the comparative advantage in an energy-related productivity lead to the export performance through inducement of comparative advantage. This empirical analysis finds that the environment-related efficiency measured by energy use and pollution emissions as unit of production positively affect the export performance of an industry. The empirical results further show that the impact of the efficiency depends on industrial characteristics. In particular, the efficiency has smaller impact on export performance in relatively less footloose industries.

Attention is paid to impact of energy and environmental regulation on economy in this dissertation. The dissertation throughout all essays makes clear that sustainable development depends on the economic approach to mitigate the global environmental issue. It is hoped that the dissertation contributes a small amount to a step to solve the environmental problems in the following two respects. At first, it offers to a meaning to consider energy policy and economic growth under the constraint of natural resources which are substitute for one natural resource in depending on the economic growth. The secondly, the dissertation offers to the observed comparative advantage with respect to energy use and pollution emissions productivity.

On the other hand, there are many rooms for further consideration, and there is space for no more than an indication of these rooms. At first, further development of theory is tried, for example, endogenous growth under a constraint of natural resource and environment and recent trade theory to incorporate economic approach to internalize an externality. Both of basic theoretical structure have much in common, and these development suits my schedule. The last point is the further consideration and application of estimation method. A part of the estimation results is not obtained in line with the theory. The learning the technique of various estimations based on the characteristics of economic statistics is helpful in future work.