ENVIRONMENTAL AND ENERGY ISSUES IN AN OPEN ECONOMY

by

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Environmental and Energy Issues in an Open Economy

Thesis directed by Professor James Markusen and Assistant Professor Jonathan Hughes

The environmental and energy consequences of globalization have become an important topic of debate. My dissertation examines the interaction between environmental and energy issues and international trade. Specifically, I investigate environmental regulations and policy in an open economy.

In the first chapter, I analyze how an environmental tax on pollution from consumption affects trade flows and welfare in an open economy. In particular, I argue that the effect of an environmental tax on the direction of trade flows depends on who is directly burdened by the regulation (consumers or producers) regardless of who is the polluter. In the case of pollution generated by consumers, a tax on consumers who are the polluters tends to increase exports and reduce imports of dirty goods. This result is the opposite of the well-known effect arising from taxes on pollution-intensive industries. Stringent environmental regulations on pollution-intensive industries diminishes exports and increases imports of dirty industries. In terms of welfare, I show the importance of targeting the policy instrument to the correct source of pollution. Assuming pollution is caused by the consumption of a good, a production tax has a weak effect on increasing welfare through reducing pollution. Furthermore, welfare can fall if the production tax ratio is too high, leading to reduced national income.

The second chapter is motivated by recent trends in the U.S. economy: increasing imports from China, decreasing energy consumption, and increasing output. There are two primary theoretical approaches related to the relationship between energy use in U.S. manufacturing and increasing imports from China: Heckscher-Ohlin (H-O) trade theory and the Pollution Haven Hypothesis (PHH). These two frameworks generate opposite predictions about the relationship between these trends. H-O theory suggests that with increased Chinese import penetration, U.S. manufacturing should move toward more energy-intensive industries and as a result, energy use in U.S. industries

should increase. Alternatively, PHH predicts that energy-intensive industries in U.S. manufacturing would relocate to other countries with more lax energy regulations. As a result, this would lead U.S. manufacturer to use less energy. To understand the determinants of energy use in U.S. manufacturing, I construct a computable general equilibrium (CGE) model of the U.S. economy using the 2005 input-output table. I find that increasing imports from China causes all manufacturing industries to use more energy. Energy use increases proportional to the output of each industry. However, the magnitude of this effect is very small. In order to help understand the magnitude of the effect, I introduce a (counter-factual) tax on energy use in U.S. manufacturing. Combining these two scenarios, increasing imports from China and an energy tax, produces an outcome consistent with the actual data: decreasing energy consumption and increasing output. Interestingly, total energy use in the U.S. manufacturing sector can decrease while at the same time U.S. welfare can increase due to its improved terms of trade. This result shows that a small energy tax can offset the increased energy use caused by Chinese import penetration, but will not reduce welfare. In addition, unlike the prediction generated by H-O theory, increasing Chinese imports causes imported intermediate inputs from China to become cheaper resulting in increased output in all sectors of U.S. manufacturing.

In the final chapter, I numerically estimate these effects using U.S. manufacturing industry-level panel data from 1997 to 2005. I decompose the effect of increasing imports from China on energy use in U.S. manufacturing into a factor substitution effect and an output scale effect. Because import penetration may be endogenous, I instrument for Chinese import penetration using Chinese share of world trade. My results indicate that increasing imports from China raises consumption of fuel and electricity. As in the simulation model, the marginal effect of Chinese import penetration is small, about 0.05% to 0.08%, but statistically significant. Interestingly, the directions of the factor substitution effects on fuel and electricity are opposite. Increasing imports from China causes a decrease in the factor ratio of fuel over labor, but an increase in the ratio of electricity over labor.

To my family

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Any errors or omissions are my own.

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CHAPTER I

The Effects of Environmental Regulation in an Open Economy: the Case of Pollution Generated by Consumers

1.1 Introduction

Most studies of environmental regulation in an open economy concern pollution generated by producers, ignoring the pollution created as a result of consumption.[1] However, a significant portion of overall pollution levels arise from consumption and this pollution creates substantial environmental problems. For example, motor vehicles generate up to half of the emissions of smog-forming volatile organic compounds (VOCs) and nitrogen oxides (NOx), and cause about half of the toxic air pollutant emissions in the US.[2] Throughout this paper, the goods which generate pollution as result of consumption are referred to as 'dirty' goods. Producers who generate pollution through production are labeled as 'dirty' industries.[3]

Data show how pollution from 'dirty' goods comprises a substantial portion of total pollution emissions. New York City (2007) estimates about 50% of CO_2 emissions are generated as a result of consumption. In addition, the consumption of goods and services in the E.U. caused 4,700Mt of CO_2 emissions in 2001. This is 500Mt higher than the reported CO_2 emissions of 4,200 Mt under the Kyoto Protocol. Similar to the E.U., in most OECD countries CO_2 emissions from consumption exceed emissions from production.[4] As the economy grows and is dominated by service industries, which are also increasingly export industries, pollution from consumption increases. Therefore,

[1] Copeland and Taylor (1994)
[2] USEPA (1993)
[3] McAusland (2008) labels producer-generated pollution as "smokestack" and consumer-generated pollution as "tailpipe".
[4] Bang et al. (2008)

reducing pollution by consumers is an important issue in environmental regulation.

Environmental regulation of pollution by consumers takes various forms, including taxes, production standards, and outright bans on pollution. This study examines how these regulations affect trade flows and welfare in an open economy. In autarky, consumers have to consume as much as domestic producers produce. Therefore, to reduce consumer-generated pollution, regulations imposed on producers can achieve the same result as regulations on consumers. However, unlike autarky, the effect of environmental regulation is different depending on who is directly burdened by the regulation. Theoretical analyses find that strict environmental regulation imposed on domestic producers weakens a country's comparative advantage in pollution intensive industries, leading to diminished exports.[5] Conversely, strict environmental regulation on consumers increases exports of the regulated goods. For example, in a small open economy in which countries face fixed world prices, an environmental regulation in the form of a consumption tax (or subsidy) discourages the consumption of regulated goods. It results in the export of these dirty goods because consumers substitute clean goods for the regulated goods.[6]

There are studies that investigate trade flows as a determinant for the optimal level of environmental taxes in an open economy compared to production and consumption taxes. Krutilla (1991) argues that in a large open economy, environmental consumption and production taxes impact on trade flows works in opposite directions because the two taxes have opposite effects on world price and trade balance. By reducing consumption, the environmental tax on consumption increases the regulating country's initial level of excess supply which places a downward pressure on world price. In the final trade equilibrium, the regulating country's excess supply will have increased in the case of consumption tax relative to the pre-regulation level. Markusen (1975) shows that optimal second-best pollution taxes will be either higher or lower than those which would fully internalize the externality, since terms of trade effects must be considered when tariff levels are exogenous.

This paper contributes to the literature by examining how environmental regulation impacts the determinants of trade flows and welfare level in the case of pollution from consumption in an open economy. It differs from previous papers such as Markusen (1975) and Krutilla (1991) by focusing on the pollution created by the consumption of dirty goods and by including environ-

[5]See Pethig (1976) and McGuire (1982).
[6]Markusen et al. (1995)

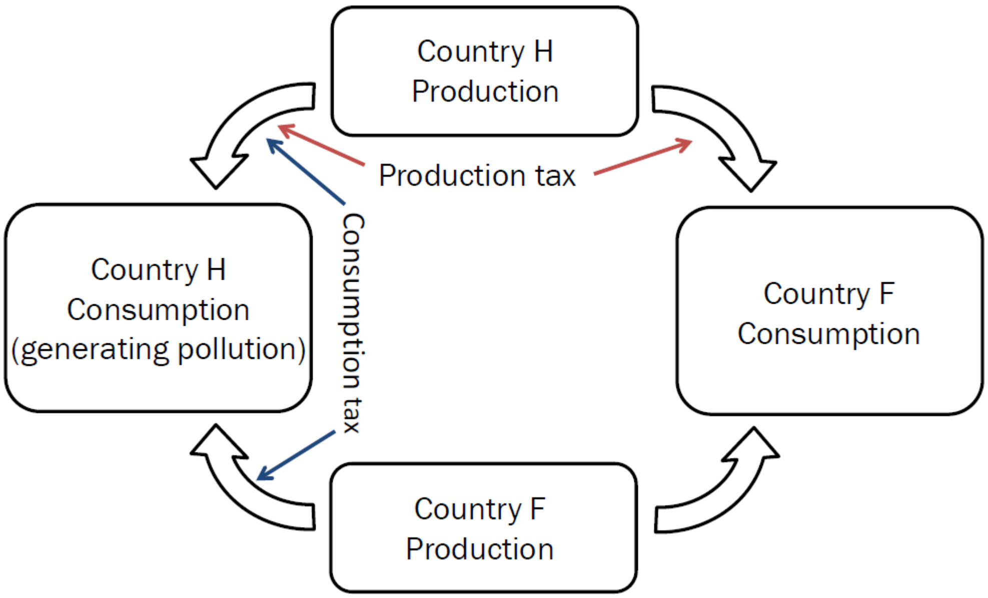


Figure 1.1: Differences in the effect of environmental taxes in an open economy

mental quality in consumer's utility. This study argues that environmental regulation imposed on producers causes trade flows to increase exports of clean goods and increase imports of dirty goods, while a consumption tax on dirty goods leads to exports of dirty goods and imports of clean goods regardless of the source of the pollution. With respect to the overall welfare, welfare levels are affected differently depending on who is the polluter and who is subject to taxes. In the case of pollution from consumers, consumption taxes increase welfare with increasing environmental quality and substitution of clean goods for dirty goods. However, production taxes have weaker effects on reducing pollution and decrease the consumption of both goods. Figure 1.1 shows why production taxes have weaker effects. In an open economy, the production taxes do not fully affect the polluter, and instead affect the goods that is domestically produced and then exported.[7] Welfare may be worse if the tax ratio is too high. This occurs because the effect of reduced income is greater than the effect of reduced pollution on the overall welfare level. Interestingly, the welfare level of a foreign country with no environmental regulation is affected in the opposite direction as the home country with imposed environmental regulations.

[7]These goods do not affect the pollution in domestic because these are consumed in other countries.

Finally, this paper also develops a computable general equilibrium model to examine the effect of environmental regulation on welfare through reduced pollution and changed income by consequential trade flows. It provides a framework with which to analyze the impacts of environmental regulation aimed at reducing pollution from consumption on trade flows and welfare in an open economy.

1.2 Conceptual Framework

This model is based on two identical countries who produce two goods. Consumers in both countries have the same preferences related to goods and environmental quality, and the same production functions.

$$U_i = U(X_i^c, Y_i^c, (1 - Z_i)) \qquad\qquad i = H, F \tag{1.1}$$

X are dirty goods which generate pollution from consumption and Y are clean goods which do not generate pollution from consumption. X and Y are substitutes for consumers in both countries. The production of X and Y do not generate pollution by assumption. The model also assumes that there is an environmental endowment and the quality of the environment is one of the factors that determines consumers' welfare in both countries. The environmental endowment is normalized to 1 and environmental quality decreases by consumption of dirty goods that generate pollution. It should be noted that boundary pollution is not considered in this model.[8] Pollution levels (Z_i) in each country are a function of the total level of consumption of dirty goods (X_i^c). Let X_{ij} be the quantity of good X produced in country i and consumed in country j.

$$Z_i = e(X_i^c) \qquad\qquad X_i^c = X_{ii} + X_{ij} \tag{1.2}$$

The home country only considers environmental regulations such as taxes or subsidies for reducing pollution from dirty goods. After imposing an environmental tax (τ_c or τ_p) on dirty goods, the consumer in the home country maximizes their utility subject to their income from wages and rent. In addition, there is no government sector; all tax collections are returned to consumers as a

[8] There is a large literature about cross-boundary pollution which has negative externalities on economic agents in a neighbor country.

lump-sum.

Let p^w denote the world price ratio of p_x^w to p_y^w which is the line, $\bar{p}p$ in Figure 1.2. It is also equal to the consumer price ratio ($p_i^c = p_{ix}^c/p_{jx}^c$) and producer price ratio ($p_i^p = p_{ix}^p/p_{jx}^p$) before environmental regulation in order to isolate the effect of environmental regulation on trade flows and welfare.

$$p^w = p_i^c = p_i^p \tag{1.3}$$

Depending on the environmental regulation imposed on producers or consumers, price distortions occur among consumption prices or production prices in the home country. Figure 1.2 shows the distortional effect of environmental regulation in the home country.[9] With a consumption tax on dirty goods, producers will continue to produce at point A under the same price ratio with world price ratio, $\bar{p}p$. However, the consumer price ratio is changed and becomes the steeper dotted line, $\bar{p'}p'$ which represents the new consumer price ratio, $p_H^c = p_{Hx}^c(1+\tau_c)/p_{Hy}^c$.

$$p^w = p_H^p < p_H^c = p^w(1+\tau_c) \tag{1.4}$$

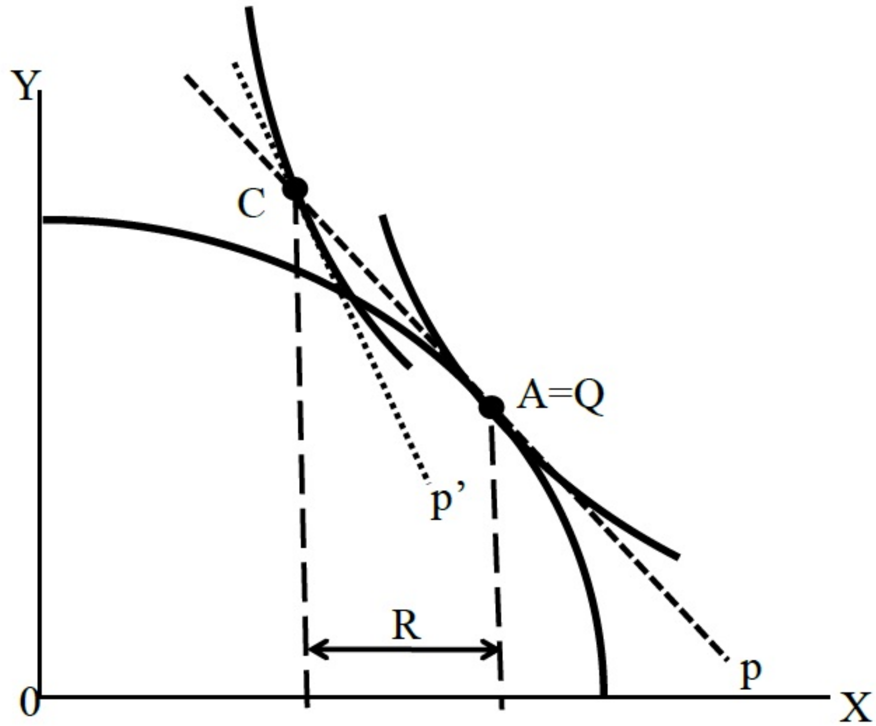
The balance of trade constraint requires trade to balance at world prices, so the consumption bundle will be changed to point C by a consumption tax on dirty goods. This regulation causes a reduction in the consumption of dirty goods by as much as 'R' in Figure 1.2 (a), and this reduced consumption also decreases pollution in the home country. In addition, the differences between the production and consumption bundles can give rise to trade between the two countries.

Compared to the previous case, in the case of a producer tax on dirty goods in the home country, environmental regulation directly affects producers in the home country. Both countries have the same amount of labor and capital, and an identical production function for both goods.

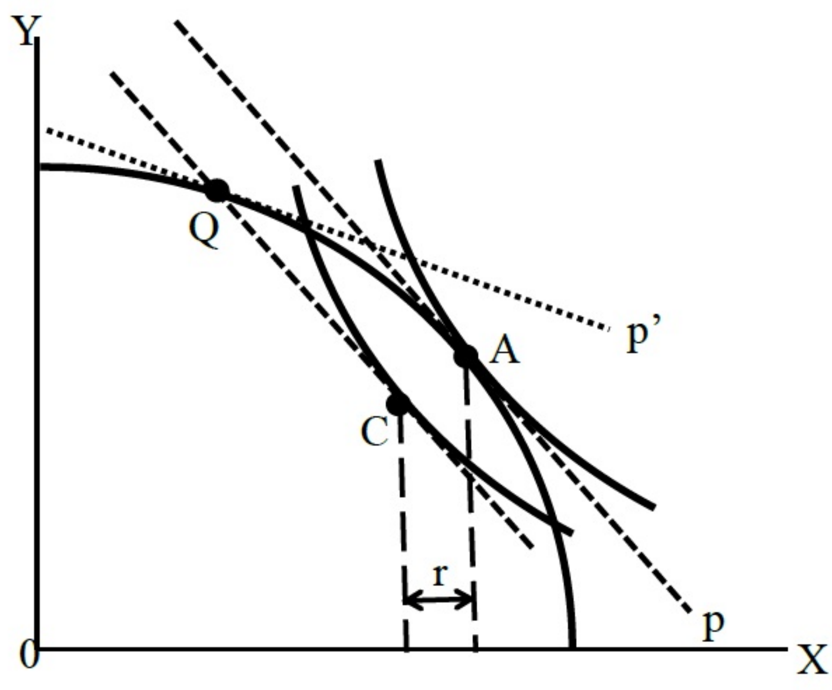
$$\begin{aligned} X_i^p &= X_{ii} + X_{ij} = f_{xi}(L_i, K_i) \\ Y_i^p &= Y_{ii} + Y_{ij} = f_{yi}(L_i, K_i) \end{aligned} \tag{1.5}$$

As a result of a producer tax in the home country, the producer price ratio changes. Figure 1.2 (b) shows how a production tax affects producers who produce dirty goods. In this case, consumers

[9] Figures are based on Markusen et al. (1995), pp. 146-149.



(a) The effect of consumption tax



(b) The effect of production tax

Figure 1.2: The effect of consumption tax and production tax

consistently face world prices, but the producer price ratio is greater than the consumer and world price ratios. The smoother dotted line, $p'\bar{p}'$ in Figure 1.2 (b) represents the new producer price ratio, $p_H^p = p_{Hx}^p(1-\tau_p)/p_{Hy}^p$. The new relationship between world and consumer price ratios, and the producer price ratio will be

$$p^w = p_H^c > p_H^p = p^w(1-\tau_p) \tag{1.6}$$

As shown in Figure 1.2 (b), imposing a producer tax on dirty goods, changes the price ratio to $p'\bar{p}'$ and the new price ratio causes the production point to become point Q. However, the consumption point is still determined by the world price ratio $\bar{p}p$ and therefore takes place at point C based on the new production point Q. As a result, consumption of dirty goods is reduced by as much as 'r' in Figure 1.2 (b). Similar to the consumption tax, the differences between the production and consumption bundles cause goods to be traded

1.2.1 Trade flows by environmental regulation

To identify the effect of environmental regulation, I hold constant other factors that affect trade flows and welfare. Therefore, in the absence of environmental regulation, the countries have no incentive to trade. That is, the free trade equilibrium without environmental regulation is equal to autarky. Point A in Figure 1.2 represents this condition in the home country where the consumer price ratio and producer price ratio are the same as world price. Additionally, I assume no trade or transport costs. Therefore, environmental regulation is the only determinant for trading.

A consumption tax distorts consumer prices and affects the level of consumption of domestically produced and consumed dirty goods (X_{hh}) as well as imported dirty goods (X_{fh}).

$$\frac{\partial X_h^c}{\partial \tau_c} = \frac{\partial X_h^c}{\partial X_{hh}} \cdot \frac{\partial X_{hh}}{\partial \tau_c} + \frac{\partial X_h^c}{\partial X_{fh}} \cdot \frac{\partial X_{fh}}{\partial \tau_c} \tag{1.7}$$

Equation (1.7) shows the decompostition of consumption changes under the consumption tax. Because both terms are clearly negative by the law of demand, consumers substitute clean goods for dirty goods due to their lower relative price. Therefore, this regulation causes consumption of dirty goods to decrease. On the other hand, the production bundle[10] is affected such that

[10]We can decompose the production bundle of dirty goods into domestic consumption and exports to the foreign

$$\frac{\partial X_h^p}{\partial \tau_c} = \frac{\partial X_h^p}{\partial X_{hh}} \cdot \frac{\partial X_{hh}}{\partial \tau_c} + \frac{\partial X_h^p}{\partial X_{hf}} \cdot \frac{\partial X_{hf}}{\partial \tau_c} \tag{1.8}$$

The first term of equation (1.8) is obviously negative consistent with the first term of the consumption case, while the second term is positive because reduced consumption of dirty goods in the home country causes producers to sell dirty goods to the foreign country. Because both terms act in opposite directions, the level of production of the dirty good in the home country does not change. A consumption tax will lead to the export of dirty goods at the same level as it reduces domestic consumption of dirty goods. Additionally, the consumption tax encourages the import of clean goods that are substitutes for the dirty goods.

On the other hand, a production tax distorts producer prices and acts as a 'supply shock' to producers. Therefore, this regulation increases marginal cost and removes the comparative advantage in producing dirty goods in the home country. Similar to the pollution haven effect demonstrated by previous studies, a production tax leads to the import of dirty goods and the export of clean goods.

Equation (1.9) captures how the consumption of dirty goods is affected by a production tax on dirty goods.

$$\frac{\partial X_h^c}{\partial \tau_p} = \frac{\partial X_h^c}{\partial X_{hh}} \cdot \frac{\partial X_{hh}}{\partial \tau_p} + \frac{\partial X_h^c}{\partial X_{fh}} \cdot \frac{\partial X_{fh}}{\partial \tau_p} \tag{1.9}$$

The first term is obviously negative because domestic production of dirty goods decreases due to higher marginal cost, while the second term is positive. The consumer price ratio remains the same as the world price ratio. Therefore, consumers prefer to keep their consumption bundle. The effect of production tax on the consumption of dirty goods is not clear. However, it is obvious that this regulation is less efficient than a consumption tax in reducing pollution from consumption. In contrast, a production tax on dirty goods leads to the import of dirty goods related to reduced domestic production. In an open economy, this decreases the national income of the home country.

These two regulations affect trade flows in opposite ways. However, this effect does not include the argument about the source of the pollution. Therefore, regardless of the pollutant, these regulations affect trade flows in opposite ways: a production tax gives rise to the import of dirty

country

goods and the export of clean goods, while a consumption tax results in the export of dirty goods and the import of clean goods.

1.2.2 Environmental regulation and welfare change

Environmental regulation potentially affects welfare[11] in two opposite ways: 1) by increasing welfare as a result of reduced pollution and 2) by changing welfare through income changes. Obviously, environmental regulation reduces pollution without concerning who is directly burdened. Therefore, all environmental regulations increase welfare by reducing pollution. However, environmental regulations also affect the economic activities of those upon whom the regulations are imposed. Changes in the economic behaviors of agents also affect welfare. The effects of regulation on each agent are not consistent, varying depending on who is a polluter and who is directly burdened by the regulation.

The effect of a consumer tax on dirty goods could be decomposed as follows:

$$\frac{\partial U_h}{\partial \tau_c} = \underbrace{\frac{\partial U_h}{\partial X_h^c} \cdot \frac{\partial X_h^c}{\partial \tau_c}}_{(-)} + \underbrace{\frac{\partial U_h}{\partial Y_h^c} \cdot \frac{\partial Y_h^c}{\partial \tau_c}}_{(+)} + \underbrace{\frac{\partial U_h}{\partial Z_h} \cdot \frac{\partial Z_h}{\partial X_h^c} \cdot \frac{\partial X_h^c}{\partial \tau_c}}_{(+)} \tag{1.10}$$

A consumption tax in the home country causes consumers to change their consumption patterns such that they decrease consumption of dirty goods and increase consumption of clean goods. The first two terms show this effect. The first term should be negative because of decreasing consumption of dirty goods, and the second term should be positive because consumers buy clean goods instead of dirty goods. The last term shows increasing welfare as result of reduced pollution. A changing welfare level caused by reduced pollution is directly related to the amount of consumption of dirty goods. Therefore, the relationship between who is polluting and who is directly burdened by the regulation is one factor determining the welfare level. This is because the effect of regulation on reduced pollution is different depending on that relationship between who is polluting and who is directly burdened by the regulation. From this decomposition, we can expect that the change in welfare level is subject to how much dirty goods and clean goods can be substituted for each other and how much people prefer environmental quality. Therefore, a consumption tax would

[11] In this paper, welfare is defined as the maximized level of utility of consumers in each country under the given constraints. By assumption, the utility function is defined as the total consumption of dirty goods and clean goods, and environmental quality in each country.

lead to increased domestic welfare through the combination of reduced pollution and substituted consumption of the two goods. Furthermore, producers in the home country start to export dirty goods in an open economy and, as a result, national income increases.

On the other hand, the effect of a production tax in an open economy is different from the previous case. A production tax discourages production of dirty goods more than a consumption tax does. However, the effect on the consumption of dirty goods is weaker than that produced by the consumption tax, because a production tax leads to the import of dirty goods. The decomposition of a producer tax on dirty goods is

$$\begin{aligned}
\frac{\partial U_h}{\partial \tau_p} &= \frac{\partial U_h}{\partial X_h^c} \cdot \frac{\partial X_h^c}{\partial X_{hh}} \cdot \frac{\partial X_{hh}}{\partial \tau_p} + \frac{\partial U_h}{\partial X_h^c} \cdot \frac{\partial X_h^c}{\partial X_{fh}} \cdot \frac{\partial X_{fh}}{\partial \tau_p} \\
&+ \frac{\partial U_h}{\partial Y_h^c} \cdot \frac{\partial Y_h^c}{\partial Y_{hh}} \cdot \frac{\partial Y_{hh}}{\partial \tau_p} + \frac{\partial U_h}{\partial Y_h^c} \cdot \frac{\partial Y_h^c}{\partial Y_{fh}} \cdot \frac{\partial Y_{fh}}{\partial \tau_p} \\
&+ \frac{\partial U_h}{\partial Z_h} \cdot \frac{\partial Z_h}{\partial X_h^c} \cdot \frac{\partial X_h^c}{\partial X_{hh}} \cdot \frac{\partial X_{hh}}{\partial \tau_p} + \frac{\partial U_h}{\partial Z_h} \cdot \frac{\partial Z_h}{\partial X_h^c} \cdot \frac{\partial X_h^c}{\partial X_{ft}} \cdot \frac{\partial X_{ft}}{\partial \tau_p} \\
&= \underbrace{\frac{\partial U_h}{\partial X_h^c} \cdot \frac{\partial X_h^c}{\partial \tau_p}}_{(-)} + \underbrace{\frac{\partial U_h}{\partial Y_h^c} \cdot \frac{\partial Y_h^c}{\partial \tau_p}}_{(-)} + \underbrace{\frac{\partial U_h}{\partial Z_h} \cdot \frac{\partial Z_h}{\partial X_h^c} \cdot \frac{\partial X_h^c}{\partial \tau_p}}_{(+)}
\end{aligned} \tag{1.11}$$

The effect of a production tax on welfare could be simplified to the last line of equation (1.11). The first and last terms show the same effect as that caused by the consumption tax through reducing consumption of dirty goods and increasing environmental quality. However, unlike the case of a consumption tax, the second term has a negative effect on welfare. A production tax on dirty goods makes the home country poorer by decreasing national income. Increased world price due to the production tax combined with lower income causes domestic consumers to become poorer as the production tax increases. Therefore, even though the home country begins to import, they consume less goods than before the regulation and less than in the case of the consumption tax. The increased welfare caused by reduced pollution is outweighed by the decreased income in the home country, and the welfare level could end up being worse than it would have been without any environmental regulation.

1.3 Computable General Equilibrium(CGE) Model

In this section, I build up and simulate the computable general equilibrium (CGE) model to examine the effect of environmental regulation on economic outcomes in an open economy. The computable general equilibrium is also formatted based on the two-country Heckscher-Ohlin model: two identical countries, two goods produced, and a representative consumer in each country. The unique feature of this model is the pollution generated by consuming dirty goods, which reduces environmental quality.

1.3.1 Setting up the GE Model

Typically, equilibrium for all agents can be solved by optimizing profit/utility subject to the constraints they face. However, to find the general equilibrium, I convert the optimizing problems of agents to a squared system to avoid any inconsistency in the proposed solution. The first step to get the squared system is to solve for cost functions for producers and consumers. Producers minimize their costs to produce, and consumers minimize their expenditures to get utility. This gives the minimum cost of producing one unit of goods at given factor prices. Similarly, a consumer's minimum expenditure for getting one unit of utility at given commodity prices is also derived. These inequalities are the zero-profit conditions for general equilibrium. For the second step, using Shephard's lemma, I can calculate a producer's demands for inputs per unit of outputs and a consumer's demand for commodities per unit of utility. These give the market clearing conditions that total market supplies for inputs/commodities are equal to or greater than the total market demand for the inputs/commodities. Finally, in general equilibrium, income should be balanced. Because there is no government in this model, I assume that tax revenue generated by environmental regulation will be returned to the representative consumer. This creates the income balance equation.

Each inequality/equation is associated with a particular variable, called a complementary variable. Intuitively, complementary variables should ensure the related inequalities/equation in general equilibrium hold. For example, if a producer's marginal cost is greater than the marginal revenue, the goods will not be produced. This means that the output level must be zero. If a producer's marginal cost is equal to the marginal revenue, the positive level of equilibrium supply will occur in the economy. Therefore, in equilibrium, the price inequality is complementary with the quantity

	Inequalities/equation	Complementary Variable
I. Zero profit conditions		
∘ marginal cost of $X \geq$ price of X	$c_x(P_l, P_k) \geq P_x$	X
∘ marginal cost of $Y \geq$ price of Y	$c_y(P_l, P_k) \geq P_y$	Y
∘ unit expenditure for $U \geq$ price of U	$e(P_l, P_k, P_{ca}) \geq P_u$	U
II. Market clearing conditions		
∘ market supply $\geq$ demand for X	$X \geq e_{px}(P_x, P_y)\ U$	P_x
∘ market supply $\geq$ demand for Y	$Y \geq e_{py}(P_x, P_y)\ U$	P_y
∘ market supply $\geq$ demand for CA	$CA \geq e_{pca}(P_x, P_y)\ U$	P_{ca}
∘ market supply $\geq$ demand for L	$\bar{L} \geq cx_w X + cy_w Y$	P_l
∘ market supply $\geq$ demand for K	$\bar{K} \geq cx_r X + cy_r Y$	P_k
∘ market supply $\geq$ demand for U	$U \geq I/P_u$	P_u
III. Income balance condition		
	$I = p_l \bar{L} + p_k \bar{K} + p_{ca}\ CA$	I

Table 1.1: The Squared System of the General Equilibrium Model

variable, which is the activity level. For the market clearing condition, if supply exceeds demand for the factor or goods in equilibrium, its price should be zero. Therefore, this quantity condition is complementary with a price variable. The complementary variable to an income balance equation is simply the income of that agent.

In summary, the general equilibrium model with perfect competition consists of three parts: the zero-profit condition, the market clearing condition, and the income balance condition, which are complementary with activity level, price, and income, respectively. Table 1.1 shows the functional forms of derived inequalities and the associated complementary variables for calculating general equilibria depending on environmental regulation on pollution from consumption. Now, I calibrate this model with specific parameter values at the benchmark.

Consumers Consumers' preference is constant elasticity of substitution over consumption goods ($X_{c,i}$ and $Y_{c,i}$) and environmental quality in both countries. The utility function simplifies to

Cobb-Douglas.

$$U_i(X_{c,i}, Y_{c,i}, CA_i) = {X_{c,i}}^{\alpha} {Y_{c,i}}^{\beta} {CA_i}^{\gamma} \qquad where \quad i = H, F \qquad CA_i = ECA_i - POL_i \tag{1.12}$$

Let ECA denote clean air endowment, which is the original endowment of clean air, and CA denote clean air, defined as the current usable clean air. The environmental quality is modeled by endowing consumers with 'clean air (CA)' normalized to 1 in both countries.[12] $X_{c,i}$ and $Y_{c,i}$ represent the total consumption of the two goods in each country.[13] In the benchmark specification, the weights chosen for the utility function are equal to $\alpha = 0.4$, $\beta = 0.4$ and $\gamma = 0.2$ for both countries. By minimizing the consumer's expenditure problem, the unit expenditure function for utility is given by

$$P_{x,i}^{\alpha} \cdot P_{y,i}^{\beta} \cdot P_{ca,i}^{\gamma} \geq P_{u,i} \tag{1.13}$$

This inequality is the consumer's zero profit condition with the complementary variable, consumer's utility level, U_i. Optimized consumer's utility yields the market demand functions for all goods with the complementary variables, the commodity prices.

$$X_i \geq \alpha \cdot \frac{U_i \cdot P_{u,i}}{P_{x,i}} \qquad Y_i \geq \beta \cdot \frac{U_i \cdot P_{u,i}}{P_{y,i}} \tag{1.14}$$

In the same way, the demand for clean air can be also derived. However, in the case of public goods, the quantity cannot be chosen by consumers, but is decided by the amount of consumption of dirty goods, X_i in each country:

$$POL_i = X_{c,i}^2 \tag{1.15}$$

[12]For both countries, the original endowment of clean air(ECA) is set as 2 and generated pollution from consumption (POL) in the benchmark specification is assumed to be 1. Therefore, the usable clean air (CA) at the benchmark is 1.

[13]These quantities are equal to the amounts of domestic production at the benchmark specification, because there is no trade. However, after trade between two countries occurs due to environmental regulation, these quantities are determined by $X_{c,i} = X_{p,i} - X_i^e + X_i^m$ where $X_{p,i}$, X_i^e, X_i^m equal domestic production, the export, and the import, respectively.

Instead, this gives a demand price for the given amount of clean air, which is denoted as $P_{ca,i}$ in this model. It is interpreted as "willingness to pay" for clean air and is part of the solution to the model.

$$CA_i = ECA_i - POL_i \geq \gamma \cdot \frac{U_i \cdot P_{u,i}}{P_{ca,i}} \tag{1.16}$$

Producers With regard to production, both countries are also identical. Consumers in both countries have labor (L) and capital (K) with the same ratio. Production for both X and Y have constant elasticity of transformation and the elasticity of substitution between labor and capital is 1. That is, the production functions also simplify to Cobb-Douglas. By assumption, the dirty goods, X are capital-intensive, and the clean goods, Y are labor-intensive to produce. In the benchmark specification, the weights of labor inputs are equal to δ_x=0.2 for the dirty goods and δ_y=0.8 for the clean goods in both countries.[14]

$$X_i(L_{x,i}, K_{x,i}) = L_{x,i}^{\delta_x} \cdot K_{x,i}^{\theta_x} \qquad Y_i(L_{y,i}, K_{y,i}) = L_{y,i}^{\delta_y} \cdot K_{y,i}^{\theta_y} \tag{1.17}$$

Through producers' cost minimizing behavior, the marginal costs should be greater than or equal to the commodity prices in the equilibrium. These price inequalities are the zero profit conditions that are complementary with the supply quantity variables, of the two goods. With specified parameters at the benchmark, these conditions are given by

$$P_{l,i}^{\delta_x} \cdot P_{k,i}^{\theta_x} \geq P_{x,i} \tag{1.18a}$$

$$P_{l,i}^{\delta_y} \cdot P_{k,i}^{\theta_y} \geq P_{y,i} \tag{1.18b}$$

Again, using Shephard's lemma, total demands for each input are derived. For market clearing, factor supplies $(\bar{L}_i, \bar{K}_i)$ should be greater than or equal to the market demands for inputs. These quantity equations are complementary with prices of inputs, $P_{l.i}$ and $P_{k,i}$.

[14] By the assumption of the Cobb-Douglas production function, the weights of capital inputs are equal to θ_x=0.8 for the dirty goods and θ_y=0.2 for the clean goods in both countries.

Functions	Value of Parameters
Utility function	
$U(X_c, Y_c, CA)=X_c^{\alpha}\ Y_c^{\beta}\ CA^{\gamma}$	α=0.4, β=0.4, γ =0.2
Production functions	
$X(L_x, K_x)=L_x^{\delta_x}\ K_x^{\theta_x}$	δ_x=0.2, θ_x=0.8
$Y(L_y, K_y)=L_y^{\delta_y}\ K_y^{\theta_y}$	δ_y=0.8, θ_y=0.2

Table 1.2: Value of Parameters at the Benchmark

$$\bar{L}_i \geq L_{x,i} + L_{y,i} = \frac{\delta_x \cdot X_i \cdot P_{x,i} + \delta_y \cdot Y_i \cdot P_{y,i}}{P_{l,i}} \tag{1.19a}$$

$$\bar{K}_i \geq K_{x,i} + K_{y,i} = \frac{\theta_x \cdot X_i \cdot P_{x,i} + \theta_y \cdot Y_i \cdot P_{y,i}}{P_{k,i}} \tag{1.19b}$$

Last, the income balance condition is that total income should be equal to the total expenditure in each country in the equilibrium. The unique feature of the income balance condition in this model is that the value of the remaining clean air is also included in this equation to be balanced with the market clearing condition for clean air. The complementary variable to this income balance equation is the income of the representative consumer.

$$I_i = P_{l,i} \cdot \bar{L}_i + P_{k,i} \cdot \bar{K}_i + P_{ca,i} \cdot CA_i \tag{1.20}$$

Environmental regulations and trade At the benchmark specification, there is no trade between these two countries because they are identical. To examine how environmental regulations of dirty goods affect welfare and trade flows, it is necessary to introduce the regulation in one country. I assume that only country H is concerned with environmental quality, which is damaged by pollution resulting from the consumption of dirty goods, so this country regulates pollution through imposing environmental taxes. As country H starts imposing taxes, the equilibrium outcomes are affected with modified equilibrium conditions. Depending on which side has the environmental tax imposed on them, the previous system of inequalities is affected differently. In addition, the changed price ratio of the two goods as a result of taxes fosters trade between the two countries.

In the case of country H imposing a consumption tax ($ctax$) on dirty goods, the consumer price of X in H is raised by $ctax$ and the zero-profit condition for consumers in the two countries will be separately rewritten as (1.13').

$$\begin{aligned} P_{x,H} \cdot (1+ctax)^{\alpha} \cdot P_{y,H}^{\beta} \cdot P_{ca,H}^{\gamma} \geq P_{u,H} \\ P_{x,F}^{\alpha} \cdot P_{y,F}^{\beta} \cdot P_{ca,F}^{\gamma} \geq P_{u,F} \end{aligned} \tag{1.13'}$$

This consumption tax ($ctax$) on dirty goods also leads to changes in the market clearing conditions for the dirty goods in two ways: reduced domestic demand for the dirty goods, and trade caused by a changed price ratio between the two goods.

$$\begin{aligned} X_{p,H} + X_H^m \geq X_H^e + \alpha \cdot \tfrac{U_H \cdot P_{u,H}}{P_{x,H}(1+ctax)} \\ X_{p,F} + X_F^m \geq X_F^e + \beta \cdot \tfrac{U_F \cdot P_{u,F}}{P_{x,F}} \end{aligned} \tag{1.14'}$$

In the case of a production tax ($ptax$) on dirty goods, the producer's marginal revenue of X in country H is decreased by $ptax$ per unit. Therefore, the zero-profit condition for the dirty goods producer in H is different from that in F after imposing a production tax.

$$\begin{aligned} P_{l,H}^{\delta_x} \cdot P_{k,H}^{\theta_x} \geq P_{x,H}(1-ptax) \\ P_{l,F}^{\delta_x} \cdot P_{k,F}^{\theta_x} \geq P_{x,F} \end{aligned} \tag{1.18a'}$$

The market clearing condition for inputs is also affected by this production tax. The demands for labor and capital by producers of dirty goods are reduced by decreasing output level. The effect on market demand for capital in H is greater than the effect on the labor market, because dirty goods are capital-intensive.

$$\begin{aligned} \bar{L}_H \geq L_{x,H} + L_{y,H} = \tfrac{\delta_x \cdot X_H \cdot P_{x,H}(1-ptax) + \delta_y \cdot Y_H \cdot P_{y,H}}{P_{l,H}} \\ \bar{L}_F \geq L_{x,F} + L_{y,F} = \tfrac{\delta_x \cdot X_F \cdot P_{x,F} + \delta_y \cdot Y_F \cdot P_{y,F}}{P_{l,F}} \end{aligned} \tag{1.19a'}$$

$$\begin{aligned} \bar{K}_H \geq K_{x,H} + K_{y,H} = \tfrac{\theta_x \cdot X_H \cdot P_{x,H}(1-ptax) + \theta_y \cdot Y_H \cdot P_{y,H}}{P_{k,H}} \\ \bar{K}_F \geq K_{x,F} + K_{y,F} = \tfrac{\theta_x \cdot X_F \cdot P_{x,F} + \theta_y \cdot Y_F \cdot P_{y,F}}{P_{k,F}} \end{aligned} \tag{1.19b'}$$

Based on the assumption that there is no government, all tax collection returns to consumers in lump-sum style. Therefore, I add all tax collections to the income balance equation of the consumer in H.

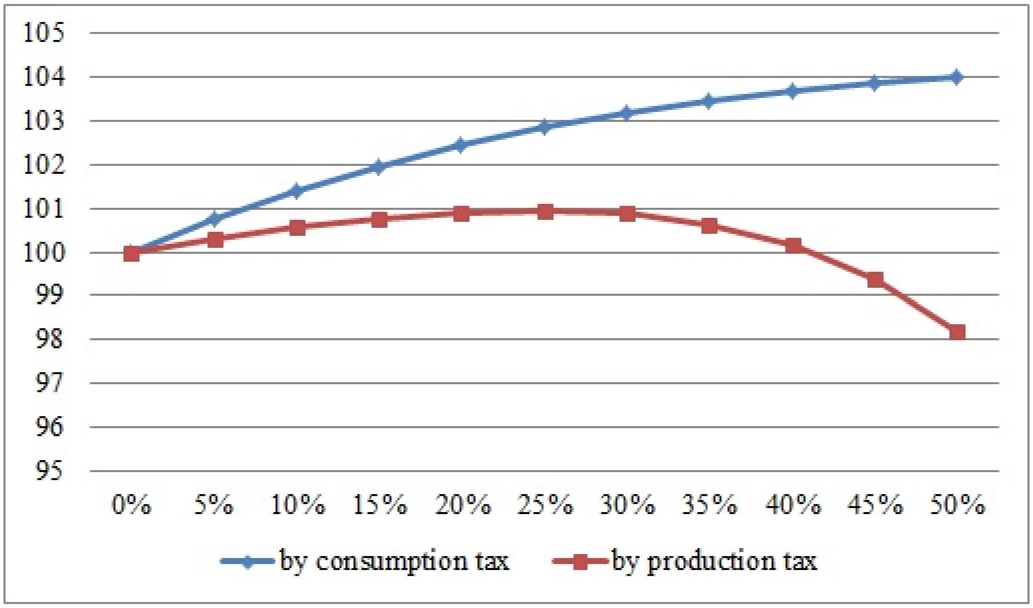
$$I_i = \begin{cases} P_{l,i} \cdot \bar{L}_i + P_{k,i} \cdot \bar{K}_i + P_{ca,i} \cdot CA_i + ctax \cdot P_{x,H} \cdot X_{c,H} & \text{with consumption tax} \\ P_{l,i} \cdot \bar{L}_i + P_{k,i} \cdot \bar{K}_i + P_{ca,i} \cdot CA_i + ptax \cdot P_{x,H} \cdot X_{p,H} & \text{with production tax} \end{cases} \quad (1.20')$$

1.3.2 Counterfactual Experiments

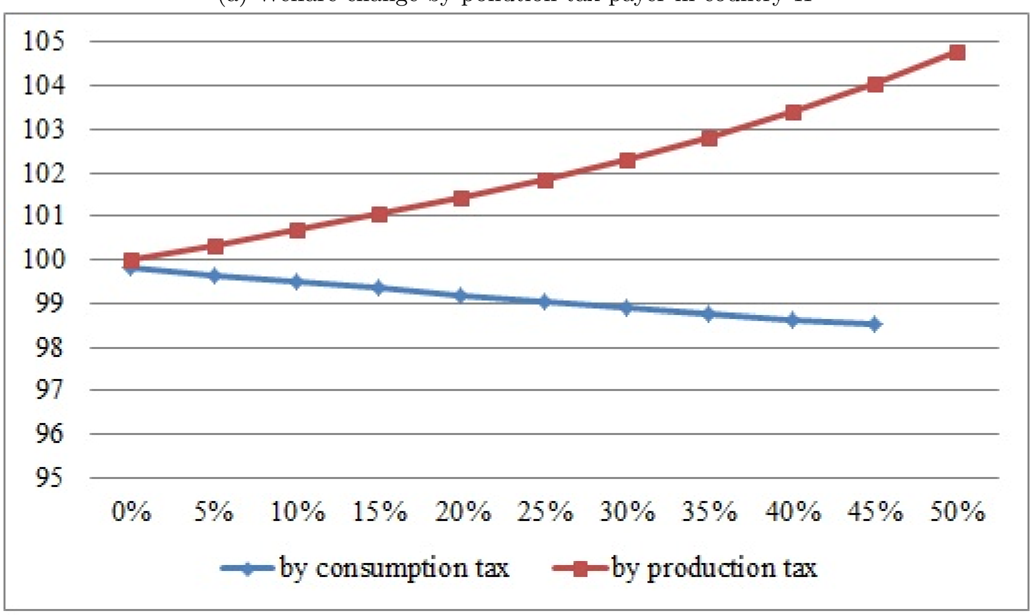
1.3.2.1 Should the production or the consumption of dirty goods be regulated?

The first question is, who should pay the pollution tax on dirty goods? I compare how welfare and pollution levels are changed based on whether the pollution tax targets the producers of dirty goods or the consumers of dirty goods. Figure 1.3 shows how welfare changes by tax payer in both countries. In country H with regulation, the graphs depict a concave shape for changing welfare according to increasing tax rates, regardless of the tax payer. Welfare increases at a low tax rates under both types of regulation because pollution is reduced. However, as environmental regulation becomes more stringent, the effect of a production tax on welfare is clearly smaller than that of a consumption tax. In the case of a consumption tax, welfare is continuously increasing, even with a high tax ratio. Even though welfare also increases with a production tax, it increases slightly initially and then rapidly decreases when the tax ratio is greater than 25%. This occurs because the effect of reduced pollution is outweighed by the reduced income caused by the production tax. In an open economy, trade between two countries is caused by imposing a production/consumption tax that affects the consumer's income level. With a production tax, a consumer in country H becomes relatively poor and therefore the welfare determined by consuming both commodities is reduced. In contrast, in the case of a consumption tax, consumers in country H substitute their consumption of dirty goods for clean goods, and producers are not affected by the changed price ratio. Therefore, welfare in country H can keep increasing only through reduced pollution. This result shows that whether the actual source of the pollution is targeted by the regulation has important effects on an open economy.

Country F with no environmental regulation is also affected by country H's environmental taxes in an open economy. Figure 1.3 (b) shows how welfare changes in country F according to the

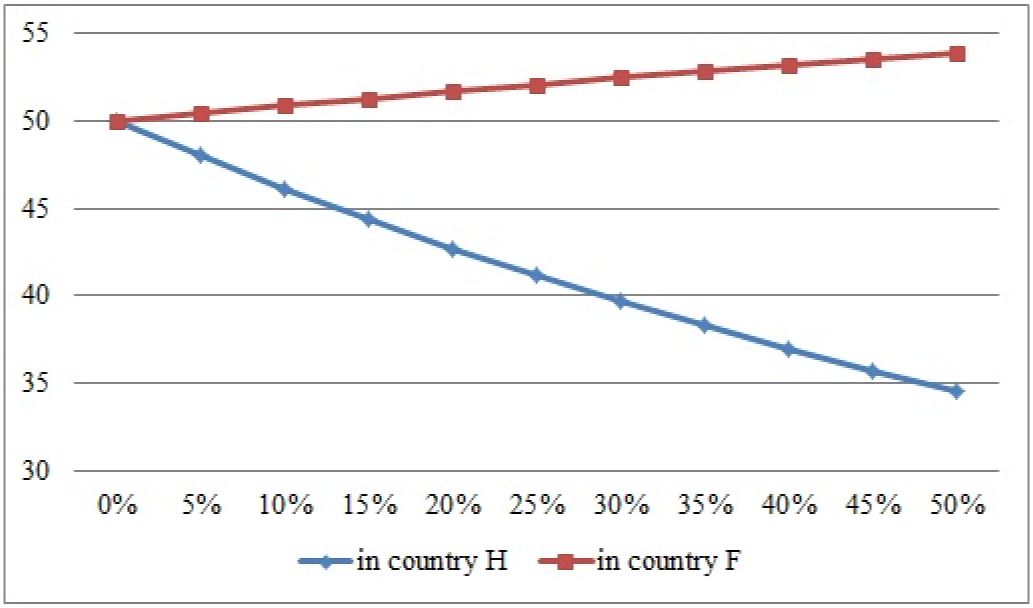


(a) Welfare change by pollution tax payer in country H

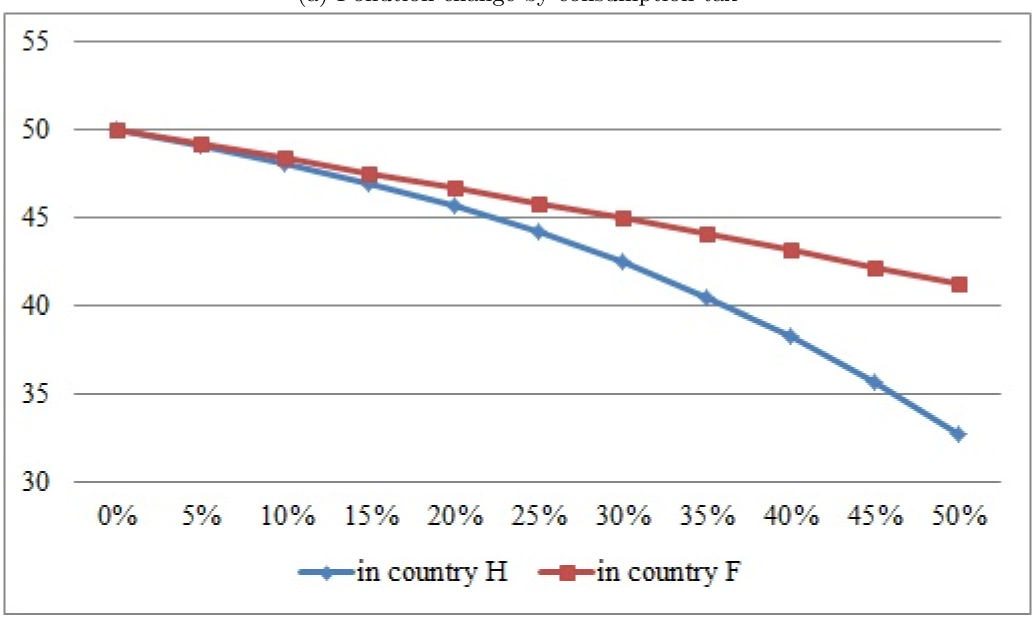


(b) Welfare change by pollution tax payer in country F

Figure 1.3: Welfare change by pollution tax payer



(a) Pollution change by consumption tax



(b) Pollution change by production tax

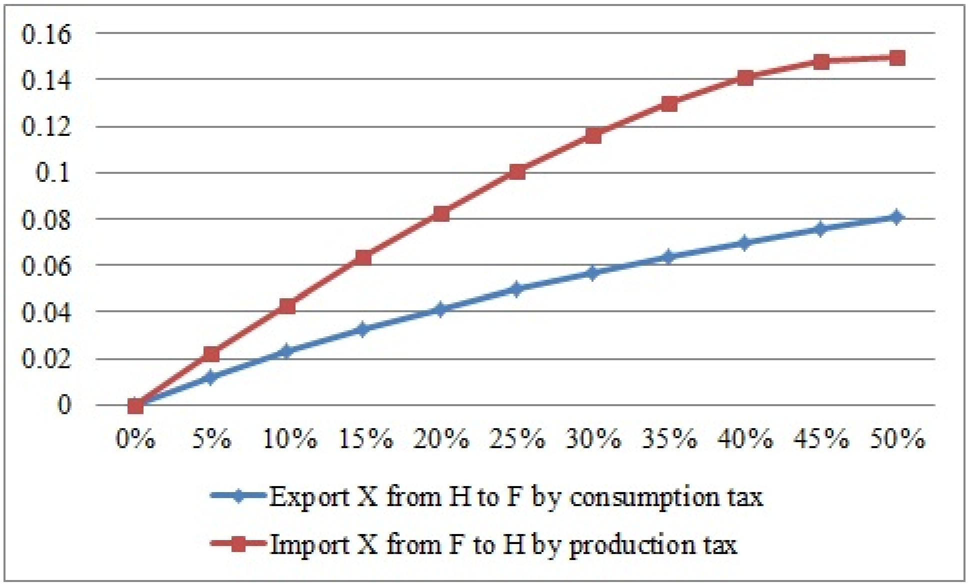
Figure 1.4: Pollution change by environmental regulations

tax payers in country H. Welfare change in country F has opposite effects depending on who the tax payer is in the trading country. Interestingly, with a consumption tax in country H, the welfare level decreases, and the pollution level increases in country F, which is the opposite effect as that caused by a production tax. Because production bundles in both countries are not significantly affected by a consumption tax, the consumption of dirty goods in country F increases as consumers in country H buy less of these goods. Therefore, increasing consumption of dirty goods leads to a welfare decrease in country F through increasing pollution levels. However, in the case of a production tax in country H, the welfare of country F increases as the income in country F also increases. This is the result of producing more dirty goods and exporting them to country H. This result shows that environmental regulations in other countries in an open economy could affect the welfare level in the home country. This points to political issues about how to regulate pollution against the actions of the other countries.

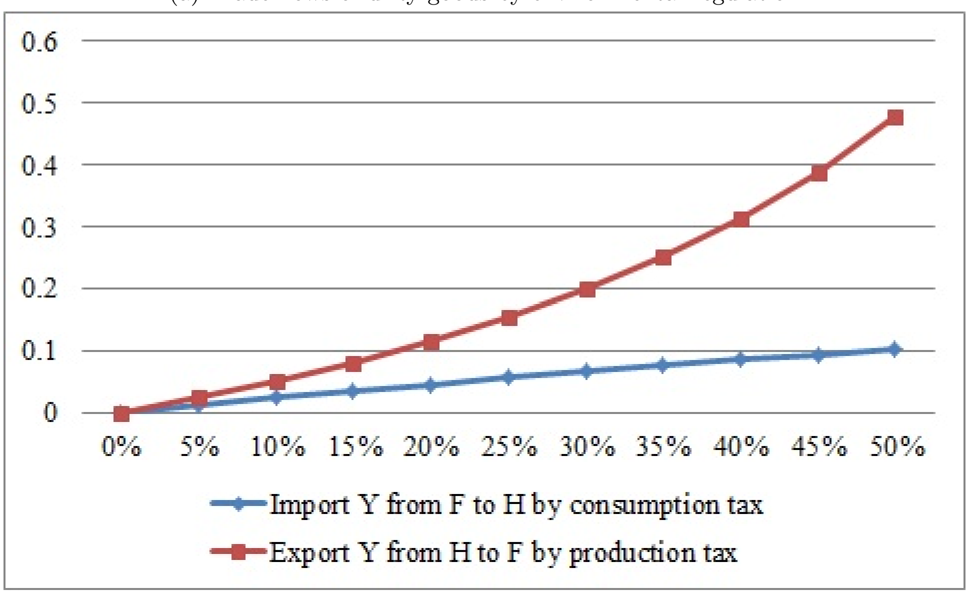
1.3.2.2 How are trade flows affected by environmental regulation of dirty goods?

The second question is how a pollution tax on dirty goods affects trade flows. Previous studies of pollution taxes on dirty industries argue that the export of goods produced by dirty industries tends to decrease as pollution taxes increase. If trade flows are equally affected by environmental regulation, it is not meaningful to examine separately the case of pollution from consumption. However, the conceptual framework predicts that the consumption tax on dirty goods will impact trade flows in opposite directions: increasing exports of dirty goods and increasing imports of clean goods caused by the consumption tax. Figure 1.5 shows the results of trade flows by tax payers in country H. A consumption tax leads to the export of dirty goods, and in contrast, a production tax on dirty goods results in the import of dirty goods. Therefore, the result of a consumption tax leading to increases in exports has the opposite effect of a pollution tax on dirty industries. Trade flows of clean goods are also affected in the opposite directions by a consumption tax and a production tax. These results show that pollution haven effect does not apply to the case of consumers who must pay environmental taxes. In other words, the effects of environmental regulation on trade flows do not differ based on who is polluting, but rather based on who is affected by the regulation.

In addition, as environmental regulation becomes more stringent, trade flows increase as a result



(a) Trade flows of dirty goods by environmental regulation



(b) Trade flows of clean goods by environmental regulation

Figure 1.5: Trade flows by environmental regulation

of both production and consumption taxes. With consumption tax, the amount of imports and exports are balanced. That is, the trade occurs along with changes in consumption patterns in country H. However, in the case of a production tax, imports of the dirty goods from country F are much bigger than the export of clean goods to country F. This trade deficit results in country H getting poorer, and it affects the national income level in an open economy.

1.4 Conclusion

I developed a two-country CGE model for the effect of environmental regulation on pollution in an open economy focusing on the case of pollution caused by consumption of dirty goods. Although pollution caused by consumption constitutes a significant portion of overall pollution, the effect of environmental regulation on these pollution levels has not been examined. In addition, in an open economy, environmental regulations on pollution resulting from consumption affect trade flows in the opposite direction of regulations on producer generated pollution.

With respect to welfare levels, both consumption and production taxes on dirty goods in the home country lead to an increase in welfare at a low tax rate. However, the effect of a consumption tax on pollution is greater than that caused by a production tax. In addition, production taxes cause a decrease in welfare if the tax rate is greater than 25%. This means that the effect of reduced pollution on welfare level is outweighed by decreasing national income caused by the production tax. From this result, I demonstrate that environmental tax should be imposed directly on consumers in the case of pollution caused by consumption of dirty goods to improve welfare by reducing pollution in an open economy. A production tax could negatively affect welfare in the home country. Interestingly, the effects of environmental regulation in the home country are in the opposite direction of the effects on the foreign country depending on who is regulated in the home country. A consumption tax on dirty goods also increases welfare in the foreign country, while a production tax decreases welfare in the foreign country. This result suggests that there are political implications for the foreign country in determining how to handle the effects of the home country's environmental regulations. In addition, effects on the global welfare caused by the home country's regulations must also be considered.

The effect of environmental regulations on trade flows also follows the prediction. When the home country regulates pollution from consumers with a consumption tax, the results do not match the pollution haven effect which predicts decreasing exports and increasing imports of the regulated goods. Instead, exports of dirty goods from the home country to the foreign country are increased, and imports of clean goods from the foreign country to the home country are increased. With a production tax on dirty goods, the effects of environmental regulation on trade flows are more pronounced. While the direction of trade is opposite to that caused by the consumption tax, as the previous studies show, this regulation generates national income effect through trade deficits.

CHAPTER II

Energy Use in U.S. Manufacturing and Increasing Imports from China: CGE Approach

2.1 Introduction

Recent trends in the U.S. economy have been marked by decreasing energy consumption in manufacturing alongside increasing outputs in manufacturing and increasing imports from China. For this study, I examine the relationship between energy use in U.S. manufacturing and increasing imports from China. Imports from China have dramatically increased over the last several decades. U.S. imports from China totaled $399.3 billion in 2011, a 9.4% increase ($34.4 billion) from 2010, and up 299% since 2000.[1] At the same time, as illustrated in Figure 2.1, energy use in U.S. manufacturing has been declining since 1998, while the real value of manufacturing output has been increasing. Energy consumption by U.S. manufacturers declined by 3.8% from 2002 to 2006 and the real value of manufacturing output increased about 10% during the same period.

The conventional wisdom related to the relationship between energy use in U.S. manufacturing and increasing imports from China typically follows two primary theoretical frameworks: Heckscher-Ohlin (H-O) trade theory and the Pollution Haven Hypothesis (PHH). These two models generate opposite predictions about this relationship. H-O theory states that the structure of U.S. manufacturing should move toward more energy-intensive industries and as a result, energy use in U.S. industries should increase when Chinese import penetration is high.[2] Chinese import penetration to

[1]Source: Office of the United States Trade Representative, http://www.ustr.gov/countries-regions/china.

[2]The U.S. is an energy-abundant country and the energy price is cheaper than other countries. Therefore, the U.S. relatively specialized in energy-intensive industries compared to China. On the other hand, China has cheap labor and comparative advantage in labor-intensive industries.

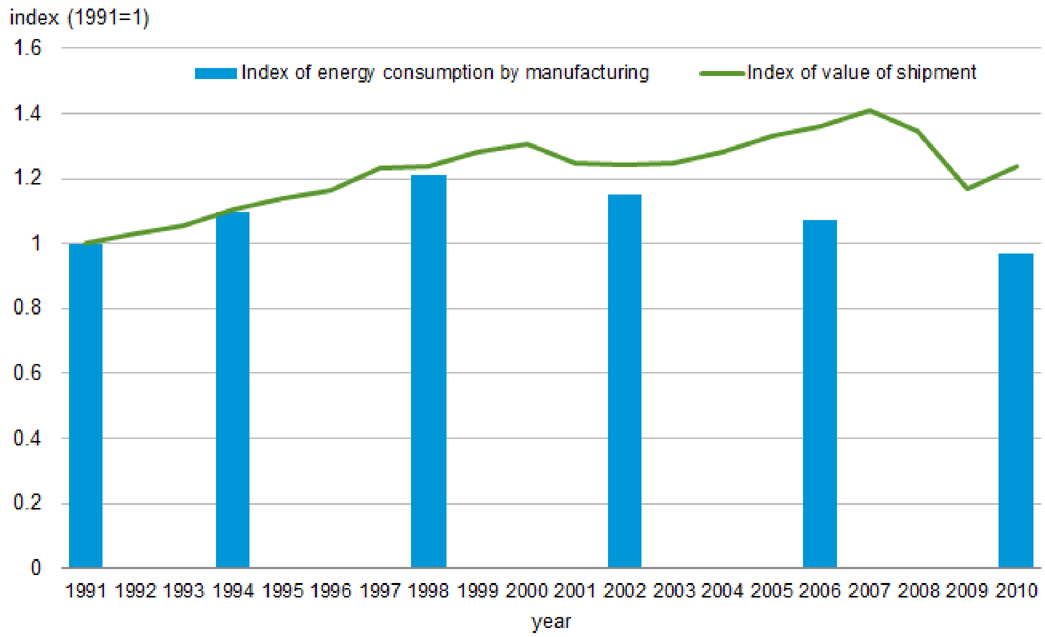


Figure 2.1: Total energy consumption and value of shipments by U.S. manufacturing

Value of shipment is based on monetary value of shipment collected from the U.S. Census Bureau, Source: U.S. Energy Information Administration

the U.S. has increased for both energy- and labor-intensive industries, but clearly labor-intensive industries face higher import penetration from China compared to energy-intensive industries. Faced with higher import penetration from China, labor-intensive industries in the U.S. should shrink, and energy-intensive industries should expand according to this theory.[3] However, as shown in Figure 2.2, energy use in energy-intensive industries such as chemicals and primary metals has not kept pace with output as these industries have grown due to increasing imports from China.[4] As an alternative to the H-O theory, PHH expects that energy-intensive industries in U.S. manufacturing would relocate to other countries with more lax energy regulations. As a result, U.S. manufacturing should end up using less energy. The declining energy intensity[5] in energy-intensive industries clearly illustrates this change. This trend may be caused by energy regulations governed by the U.S. Environmental Protection Agency (EPA). Policies designed to reduce energy use by U.S. manufacturers have been the subject of much debate between the EPA and U.S. manufacturers. These

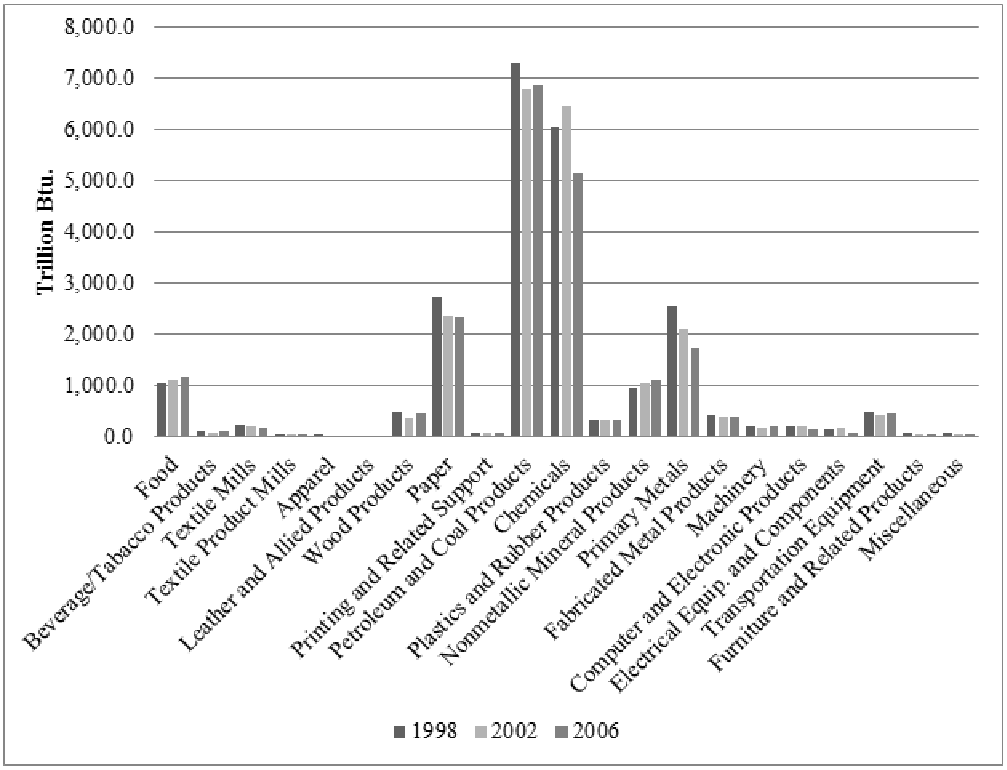
[3]Chinese import penetration pattern by industries will be shown in the next chapter.
[4]EIA, Manufacturing Energy Consumption Survey, 1998, 2002 and 2006
[5]Energy intensity is calculated by energy consumption divided by output. This is declining specially in energy-intensive industries. See Table A.3 in Appendix.

regulations and policies have caused U.S. manufacturers to reduce energy use through increasing efficiency or implementing 'greener' technology.[6]

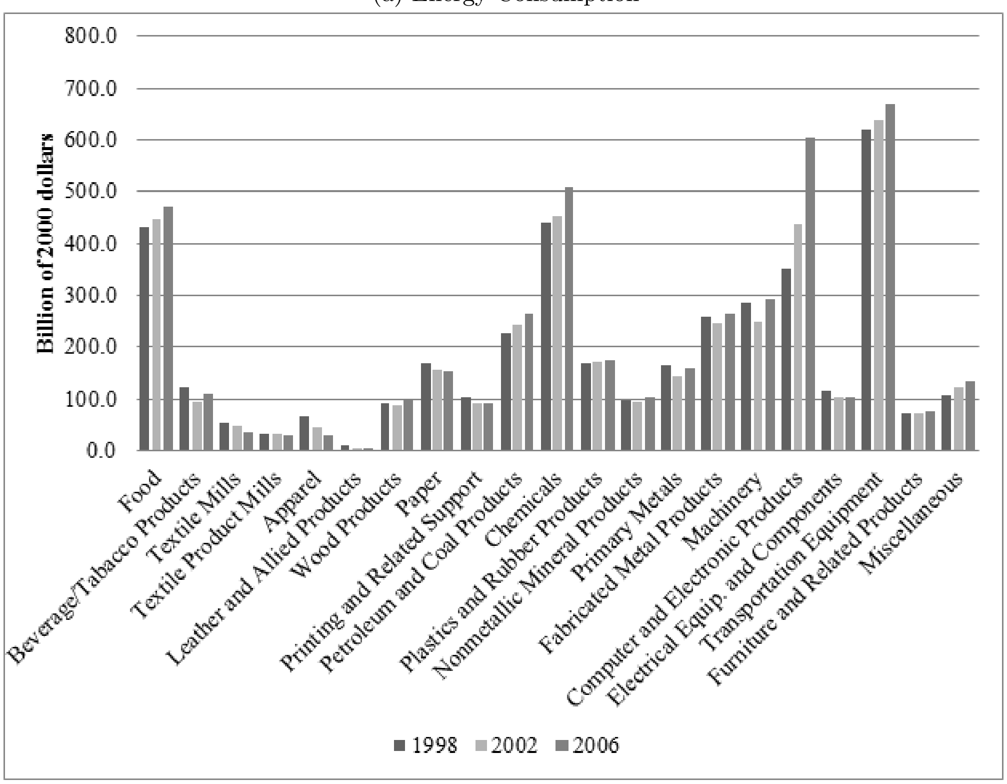
To identify the determinants of energy use in U.S. manufacturing, I construct a computable general equilibrium (CGE) model of the U.S. economy using the 2005 input-output table and simulate several scenarios related to a Chinese import shock (due to a price shock) with or without an offsetting energy tax. Specifically, to examine the effect of increasing imports from China on energy use in U.S. manufacturing, the value of imports is divided into two groups: China and the rest of world. I also use a (counter-factual) tax on energy use in U.S. manufacturing. This represents a particularly stringent U.S. environmental policy. Conceptually, the energy tax is a useful proxy for domestic environmental policies that result in higher energy costs.

The numerical results show that increasing imports from China causes all manufacturing industries to use more energy, proportionally increasing the output of each industry. Without an energy tax, the U.S.'s comparative advantage in energy-intensive industries leads it to use more energy as imports from China increase. However, the magnitude of the effect is very small. In order to help understand the magnitude of the effect, I introduce a (counter-factual) tax on energy use in U.S. manufacturing. An energy tax can cause the U.S. to use less energy because there will be substitution away from energy-intensive industries and reduced energy use within industries. U.S. manufacturers display a highly sensitive response to the enactment of energy taxes such that a 1% increase in energy tax results in a 1% falls in energy consumption and 0.1% decrease in output, with all other prices held constant. However, each industry responds differently to energy taxes depending on factor intensity. Higher energy-intensive industries reduce energy use more than other industries in response to an energy tax. Combining these two scenarios, increasing imports from China and an energy tax in the U.S., can produce an outcome consistent with the actual data: decreasing energy consumption and increasing output. Interestingly, total energy use in the U.S. manufacturing sector can decrease, at the same time as U.S. welfare increases due to its improved terms of trade. This result demonstrates that a small energy tax can offset the increased energy use caused by Chinese import penetration, but will not reduce welfare. In addition, unlike the prediction of H-O theory, increasing Chinese imports also cause imported intermediate inputs from

[6] For example, Porter (1991) argues that environmental regulations are actually as a net positive force driving private firms energy-efficient and the economy as a whole to become more competitive in an open economy.



(a) Energy Consumption



(b) Output

Figure 2.2: Energy Consumption and Output in US Manufacturing by NAICS

Source: U.S. Energy Information Administration, Manufacturing Energy Consumption Surveys and U.S. Department of Commerce, Bureau of Economic Analysis (BEA)

China to become cheaper and result in increased outputs in all sectors of U.S. manufacturing.

Even though a number of studies have examined the relationship between trade and environmental issues, the effects of trade on energy use have not been fully explored. Cole (2006) points out that it is important to understand the extent to which trade influences the common underlying cause of air pollution, namely national and international energy use. Based on the theoretical model of Antweiler et al. (2001), he empirically shows that trade liberalization is likely to increase per capita energy use for the mean country within the sample. His results also indicate that regulations and technological improvements are not keeping pace with the growth of GNP.

An extensive literature documents the effects of import penetration from low-wage countries on labor market outcomes, in particular employment and wages. These studies consistently find that increasing import penetration reduces employment and real wages (Revenga (1992), Hine and Wright (1998)). Hine and Wright (1998) examine the relationship between trade with low wage economies and U.K. manufacturing. Their results suggest that job loss and lower real wages occur as a result of increasing imports. Bernard et al. (2006) investigate the relationship between imports from low-wage countries and the reallocation of the U.S. manufacturing sector within and across industries at the plant level. They find that plant survival and growth are negatively associated with industry exposure to imports from low-wage countries. Since energy is also an important input to manufacturing, it is surprising that the relationship between imports and energy use is rarely examined.

Unlike Cole (2006), this paper focuses on the effect of increasing imports from China on the U.S. manufacturing sector, rather than the effect of general trade liberalization on national energy use. In addition, I investigate how policies to reduce national energy use may offset the effect of trade.

The rest of this chapter is organized as follows. In Section 2, I describe the theoretical framework using a modified H-O model with energy tax. In Section 3, I explain the U.S. input-output table I use for the calibration. Section 4 calibrates the model using the U.S. input-output table for the base year 2005. The results are discussed in Section 5.

2.2 Theoretical Framework

In this section, I modify the Hechscher-Ohlin model by adding an energy tax as a government policy to reduce energy use in response to increased imports from the South. This gives the prediction of the determinants of energy use in the manufacturing sector in an open economy.

2.2.1 Description

- There are two countries: the North and the South(*).
- There are two production sectors: Manufacturing and Energy.
- In the manufacturing sector, there are n industries. Manufacturing goods are produced by combining two inputs: energy and labor. The factor prices are given as w, m respectively for labor and energy. The factor-price ratio is $\frac{w}{m} > \frac{w^*}{m^*}$.
- The energy sector produces Y_E in the domestic country using a given resource(R) and capital(K). The energy output is transformed into domestic use and export (E_{EX}) and the domestic use is demanded only by manufacturing producers.
- Production in both sectors is assumed as constant returns to scale and perfect competition.
- For all sectors, manufacturing goods and energy are traded. The Armington aggregation is assumed for imported goods.
- The consumer's utility is decided only by consumption of manufacturing goods. The imported and domestic goods in a sector i are not perfectly substituted. They are aggregated by the Armington assumption.
- The energy tax, t_E increases the energy price m to $m(1+t_E)$. $(0 \leq t_E \leq 1)$

2.2.2 Production: Manufacturing sector

Let Y_i be the output level of manufacturing industry i, and L_i and E_i be the two inputs, labor and energy, respectively.

$$Y_i = L_i^{\alpha} E^{(1-\alpha_i)} \tag{2.1}$$

Minimizing the cost function, the energy demand function is derived as a function of the factor-price ratio and output.

$$E_i(Y_i; w, m) = \left(\frac{1-\alpha_i}{\alpha_i}\right)^{\alpha_i} \left(\frac{w}{m}\right)^{\alpha_i} Y_i \tag{2.2}$$

The manufacturing output is traded. That is, I assume that the manufacturing output is transformed to domestic consumption and exports using constant elasticity of transformation. They are perfectly transformable for producers. Therefore,

$$Y_i = C_i^D + EX_i \tag{2.3}$$

2.2.3 Production: Energy sector

Energy is produced by a given resource and capital in the economy.

$$Y_E = R^{\psi} K^{(1-\psi)} \tag{2.4}$$

The energy output is transformed into domestic uses in the manufacturing sector and exports. The energy producer is indifferent between the domestic and foreign markets. Therefore, they are perfectly transformed.

$$Y_E = \sum_i E_i^D + E_{EX} \tag{2.5}$$

Energy is also imported. Imported energy is used only by manufacturers. For manufacturers, domestic energy and imported energy are not perfectly substituted. That is, I assume Armington elasticity between the two types of energy. This means that the elasticity of substitution, $\frac{1}{1-\rho}$ is greater than one.

$$E_i = ARM(E_i^D, E_i^M) = [\xi_i E_i^{D\rho} + (1-\xi_i) E_i^{M\rho}]^{\frac{1}{\rho}} \tag{2.6}$$

2.2.4 Consumption

The consumer demands only manufacturing goods. The utility function is given by the Cobb-Douglas function,

$$U = \prod_i C_i^{\gamma_i} \qquad\qquad \sum_i \gamma_i = 1 \tag{2.7}$$

By maximizing the consumer's utility, the consumption level of a manufacturing sector i is

$$C_i = \frac{\gamma_i}{P_i^A} \cdot I \tag{2.8}$$

where I is the total expenditure on goods from sector i and P_i^A is the price index of Armington composition of goods from sector i. The consumption of goods from sector i is combined with the domestically produced goods and imported goods of the sector.

$$C_i = ARM(C_i^D, C_i^M) = [\mu_i C_i^{D\rho} + (1-\mu_i) C_i^{M\rho}]^{\frac{1}{\rho}} \tag{2.9}$$

The elasticity of substitution is $\sigma = \frac{1}{1-\rho}$. The domestically produced goods and imported goods can be derived as a function of total consumption of the sector.

$$\begin{aligned} C_i^D &= \left(\frac{\mu_i P_i^A}{P_i^d}\right)^{\frac{1}{1-\rho}} C_i \\ C_i^M &= \left(\frac{(1-\mu_i) P_i^A}{(1+\tau_i) P_i^m}\right)^{\frac{1}{1-\rho}} C_i \end{aligned} \tag{2.10}$$

2.2.5 Solutions

First of all, the amount of imported goods is decided by the relative price ratio between domestic goods and imported goods, and consumption share between these goods. Using equation (2.10), I can rewrite the imported manufacturing goods of sector i as

$$C_i^M = \left[\frac{P_i^d}{(1+\tau_i)P_i^m}\right]^{\frac{1}{1-\rho}} \left(\frac{1-\mu}{\mu}\right)^{\frac{1}{1-\rho}} C_i^D \tag{2.11}$$

The total derivative of energy demand function for the manufacturing sector i is

$$dE_i(Y_i; m, w) = \Omega \cdot d(w/m) + \Lambda \cdot dY_i \qquad \text{where} \quad \Omega, \Lambda > 0 \tag{2.12}$$

$$\begin{aligned} d(\tfrac{w}{m}) &= A \cdot dP_i^m && \text{where} \quad A > 0 \\ dY_i &= B \cdot dP_i^m && \text{where} \quad B < 0 \\ dP_i^m &= C \cdot dC_i^m && \text{where} \quad C < 0 \end{aligned} \tag{2.13}$$

To examine the effect of imports on energy use,

$$\frac{dE_i(Y_i; m, w)}{dC_i^M} = \underbrace{\Omega \cdot A \cdot C \cdot \frac{d(w/m)}{dC_i^M}}_{\text{factor substitution effect}} + \underbrace{\Lambda \cdot B \cdot C \cdot \frac{dY_i}{dC_i^M}}_{\text{output scale effect}} \tag{2.14}$$

When imports from the South increase, the effect on energy demand can be divided into two components: the factor substitution effect and the output scale effect. The first term in equation (2.14) shows the substitution effect between factors caused by changing the factor-price ratio between energy and labor. According to the factor price equalization, imports from the South lower the relative wage in the North. Regardless of the characteristics of a sector such as factor intensity, a changed input-price ratio leads to an increased demand for labor and reduced use of energy. The second term in equation (2.14) shows the output scale effect caused by trade. Openness to the South will alter the output level of each sector in a manner that depends on the price ratio of domestic goods to imported goods. Total consumption of sector i is increased by the decreased price index of sector i, which causes the output level in sector i to increase. The output scale effect of energy demand dominates the factor substitution effect. Therefore, it causes the North to use more energy after trading. However, if the North imposes an energy tax on energy demand for production, the energy price is changed to $m(1 + t_E)$ from m. This policy augments the factor substitution effect, and the factor substitution effect and the output scale effect work in opposite directions. Depending on sector characteristics such as energy intensity, energy use in each sector could increase or decrease with an additional energy policy.

2.3 Data: the US Input-Output Table

To analyze the model above, I use the U.S. input-output (IO) table for the base year 2005. In this section, I provide an overview of the typical structure of IO tables and examine specific features of the U.S. economy, especially focusing the energy use in manufacturing.

2.3.1 IO tables: An Overview

An IO table describes the flows among the various sectors of the economy to present a static image for a given year. Figure 2.3 shows the structure of a typical IO table. Each row of intermediate inputs contains transactions of the output of a sector. These transactions are broadly broken down by intermediate use and final consumption. For example, the value of cell DI_{ij} in the domestic intermediate use matrix shows how much sector j uses the products from sector i as intermediate inputs. The domestic intermediate use matrix (DI) means the intermediate uses which are produced domestically, while the imported intermediate use matrix (II) contains the imported intermediate uses for each sector. Final consumption is divided into three parts: private consumption (C), government consumption(G), and investment(I). There are also domestic and imported goods and services in final consumption. Finally, trade is also shown in the IO table. Exports are depicted in the columnn, E, and the columns of imports (M) with tariffs should be excluded from calculations of the domestic outputs.

The columns of intermediate use show the cost structure of production activities: intermediate inputs, compensation to labor and capital, and taxes on production. If an IO table is balanced, then the sum of the columns of each production sector should equal the sum of the rows of the each production sector because total input equals total output.

2.3.2 The U.S. Input-Output Table in 2005

I obtain the U.S. input-output table from the OECD website.[7] The format of this IO table corresponds exactly to the description of an IO table provided in the previous section.[8] For simplicity, I have aggregated sectors into three parts: energy, manufacturing and an aggregation of all other industries. The energy sector includes two industries: 1) mining and quarrying, and 2)

[7] www.oecd.org/sti/inputoutput/

[8] The U.S. IO table in 2005 is attached in Appendix B.

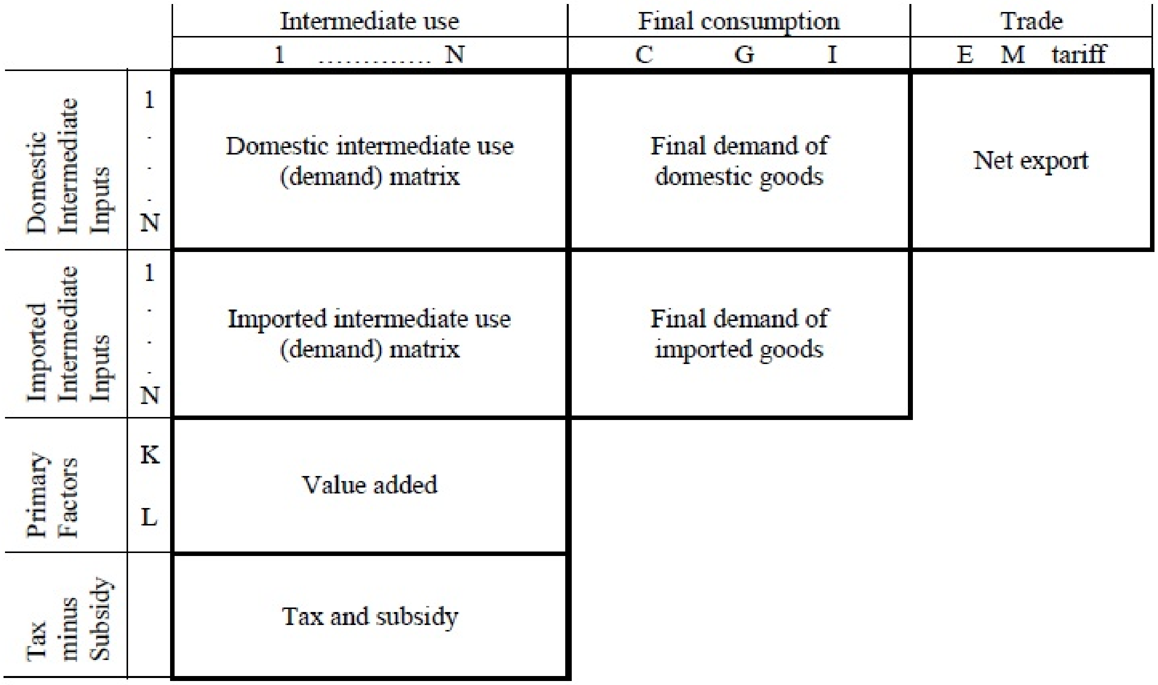


Figure 2.3: Structure of IO table

utilities (electricity, gas and water supply). The manufacturing sector includes 15 detailed industries according to IO classification. Table 2.1 shows the list of industry classifications used in the numerical analysis. All remaining sectors are aggregated into the sector 'other industries' which includes agriculture, construction, and services.

I focus on energy use in the manufacturing sector. Among manufacturing industries, the industry defined as 'coke, refined petroleum products and nuclear fuel' also should be considered an energy sector. Therefore, I examine how three forms of energy use, including refined petroleum, within the manufacturing sector are affected by increasing imports from China combined with energy tax. Table 2.1 shows how energy use is distributed across industrial sectors. Mining and quarrying is mostly used by the energy sector. The refined petroleum industry is the biggest consumer for mining and quarrying. The manufacturing sector uses about 21.7% of the electricity and 26.8% of the refined petroleum. These numbers show that energy is one of the important intermediate inputs for producing manufactured goods. The columns of energy cost share in Table 2.1 show the ratio of energy cost related to total production cost. These columns reveal that the electricity cost share is quite similar across industries, while the fuel cost share of chemical, rubber,

Table 2.1: Energy Consumption of Production Sectors in the U.S. IO table

		Proportion of energy use (%)			Energy cost share(%)		
	Sectors	1	2	7	1	2	7
	Energy						
1	Mining and quarrying	10.5	1.4	3.5	13.64	0.03	2.80
2	Electricity, gas and water supply	23.0	1.7	1.8	28.10	0.00	1.40
	Manufacturing						
3	Food products, beverages and tobacco	0.1	3.7	0.7	0.09	13.40	0.32
4	Textiles, textile products leather and footwear	0.0	0.5	0.2	0.09	0.90	0.70
5	W.ood and products of wood and cork	0.0	0.4	0.2	0.04	0.07	0.49
6	Pulp, paper, paper products, printing	0.2	2.2	1.1	0.18	0.20	0.68
7	Coke, refined petroleum products and nuclear fuel	51.6	2.9	12.1	58.81	0.08	8.50
8	Chemicals and chemical products	3.0	3.3	8.3	2.59	0.49	4.48
9	Rubber and plastics products	0.1	1.0	1.0	0.14	0.20	1.58
10	Other non-metallic mineral products	1.4	1.3	0.2	6.55	0.08	0.61
11	Basic metals	1.7	1.7	0.9	4.27	0.09	1.42
12	Fabricated metal products	0.1	1.3	0.5	0.10	0.05	0.58
13	Machinery and equipment n.e.c	0.0	0.7	0.4	0.07	0.04	0.45
14	Electrical and optical equipment	0.1	1.0	0.3	0.30	0.20	0.73
15	Motor vehicles, trailers and semi-trailers	0.5	0.7	0.4	0.52	0.04	0.24
16	Other transport equipment	0.0	0.3	0.3	0.04	0.05	0.49
17	Manufacturing n.e.c.; recycling	0.1	0.6	0.2	0.13	0.21	0.30
	All other sectors						
18	Other industries	7.7	75.2	67.9	0.23	0.83	1.24
	Total	100	100	100			

plastic products is much higher than other industries. These industries are traditionally considered to be energy-intensive industries. On the other hand, the food and textile industries have a high electricity cost share. Through these differences in the energy cost share, electricity and fuel are predicted to be viewed differently as a product factor, even though both are types of energy.

In order to examine how U.S. energy use in manufacturing responds to increased imports from China, the import column in the IO table should be divided into two parts: imports from China and imports from the rest of world. To construct this, I use the bilateral trade database from the OECD.[9] These data provide bilateral trade values by industry and end-use. I assume the tariff of each sector is consistent regardless of trading partners. If examined closely, the imports from China represent a very significant portion in each industry. Specially, more than 50% of imports in the industry including textiles and related products are imported from China. Interestingly, the machinery and equipment industry is also involves a substantial proportion of imports from China. The pattern of imports from China can be divided into two parts: labor-intensive industries which are traditionally predicted by trade theory and some other industries such as metal and machinery which are relatively close to be energy-intensive.

2.4 Calibration

In this section, I specify the CGE model and calibrate the model to the U.S. economy using the U.S. input-output table for the base year 2005. This allows me to analyze the effect of increased imports from China on energy use in the U.S. manufacturing sector and to examine how the energy tax offsets the effect of trade with China.

2.4.1 The Structure of the CGE Model

Figure 2.4(a) provides an overview of the CGE model with the flows of goods and factors in an economy. The domestic output of sector i, Y_i, is transformed into domestic consumption, DU_i, and exports, EX_i. Domestic consumption is also divided into two categories: intermediate inputs, II and final consumption, FC_i^D.[10] Utility is decided by aggregating all final consumption of outputs

[9] The STAN Bilateral Trade Database from www.oecd.org/sti/btd

[10] In the original IO table, the final consumption is also divided into private consumption, government consumption and investment. However, in this model I assume that the consumer demands all of these types of consumption, so I do not introduce the government and investment. Therefore, the consumer also collects all tax revenue later.

from all sectors. Additionally, consumers also demand the imported goods of each sector. Taxes are excluded in this part.

Figure 2.4(b) shows the structure of the production side in more detail. The output of sector i is produced by energy, intermediate inputs and composite factor. Labor (L_i), capital (K_i) and service intermediate inputs (SR_i) are aggregated into the composite factor. This composite factor is combined with intermediate inputs from other sectors (II_i) and energy (E_i) to produce the final output. There are two types of energy and intermediates inputs: domestic and imported.

2.4.2 The Functional Forms of the CGE Model

To calibrate the model using the IO table, I construct all specific functional forms of each sector. Calibrated forms of the functions of each sector are shown below.

Production The production functions for all sectors are assumed to be CES with multiple levels of nesting. This application is typical in the representation of energy demand in production.[11]

$$C_i = SR_i^{\alpha_{sr}} L_i^{\alpha_l} K_i^{\alpha_k} \qquad \text{where} \quad \alpha_{sr} + \alpha_l + \alpha_k = 1 \tag{2.15}$$

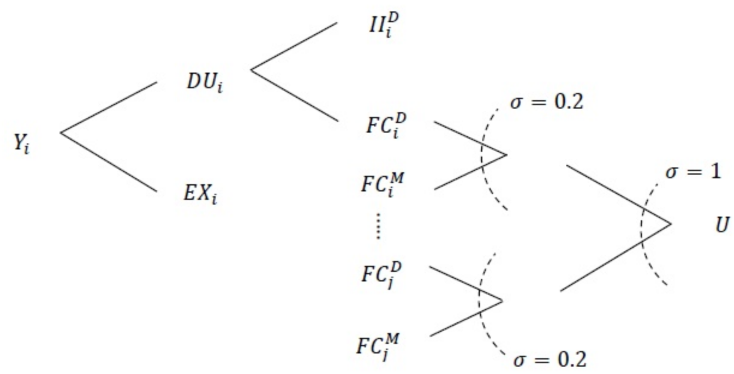
$$II_i = min[II_{ji}] \tag{2.16}$$

At the first level, primary factors such as labor (L) and capital (K), and other service sectors (SR) are used for the composite factor (C) in the Cobb-Douglas form with the constant returns to scale.[12] All intermediate inputs to a sector i from a sector j are aggregated in Leontief form by assumption. This form does not allow substitution between intermediate inputs, but significantly reduces the complexity of the model.[13] The composite factor and intermediate inputs (II) are combined in the constant elasticity substitution (CES) form.

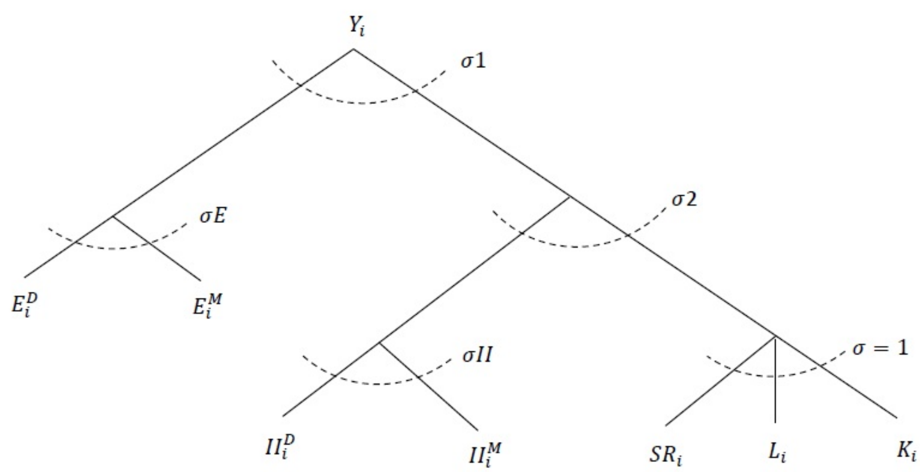
$$Y_i = A_i \left[\delta \left(\frac{E_i}{\bar{E}_i} \right)^{\rho} + (1-\delta) \left[\beta \left(\frac{II_i}{\bar{II}_i} \right)^{\epsilon} + (1-\beta) \left(\frac{C_i}{\bar{C}_i} \right)^{\epsilon} \right]^{\rho/\epsilon} \right]^{1/\rho} \tag{2.17}$$

The composite factor and intermediate inputs are combined in a CES aggregation and the two combined are further aggregated with energy in CES form again. The elasticities of substitution,

[11] There are many studies using the nested production function in energy demand. See Manne and Richels (1990).
[12] That is, $a_{sr} + a_l + a_k = 1$.
[13] Hosoe et al. (2010).



(a) Overview of CGE Model



(b) Production Structure of CGE Model

Y_i	Domestic output of a sector i
DU_i	Output domestically consumed
EX_i	Exports
FC_i^D	Final consumption of domestic output
FC_i^M	Final consumption of imported goods
E_i^D	Domestic energy intermediate inputs
E_i^M	Imported energy intermediate inputs
II_i^D	Domestic intermediate inputs of manufacturing
II_i^M	Imported intermediate inputs of manufacturing
L_i	Labor
K_i	Capital
SR_i	Service intermediate inputs
σ	Elasticity of substitution

Figure 2.4: Structure of CGE Model

Table 2.2: Selected Elasticities

Elasticity of substitution	Meaning	Selected Value
$\sigma 1$	Between composite factor and intermediate inputs	0.5
$\sigma 2$	Between energy and other inputs	0.5
σ_E	Armington elasticities for energy	0.2
σ_{II}	Armington elasticities for intermediate inputs	0.2

$\sigma 1$ and $\sigma 2$ in Figure 2.4(b) are respectively $\frac{1}{1+\rho}$ and $\frac{1}{1+\epsilon}$. For the benchmark analysis, I assume these elasticities are both 0.5.

Consumption The utility function is assumed to be a Cobb-Douglas function with constant returns to scale.

$$U = \prod_{i}^{n} \left(\frac{FC_i}{\bar{FC}_i} \right)^{\gamma_i} \qquad \text{where} \quad \sum_{i}^{n} \gamma_i = 1 \tag{2.18}$$

The utility is maximized subject to the budget constraint.

Trade Because I conduct the model in an open economy, all production factors as well as final products are traded with other countries. At the same time, the differences between domestically produced/consumed goods and exported/imported goods have to be considered. Through the CGE model, I assume that they are imperfectly substitutable with each other. This assumption, commonly known as the Armington assumption, is broadly used in CGE models of an open economy (Armington (1969)).

$$E_i = \left[\lambda_i \left(\frac{E_i^D}{\bar{E}_i^D} \right)^{\rho_E} + (1 - \lambda_i) \left(\frac{E_i^M}{\bar{E}_i^M} \right)^{\rho_E} \right]^{\frac{1}{\rho_E}} \tag{2.19}$$

$$II_{ji} = \left[\kappa_{ji} \left(\frac{II_{ji}^D}{\bar{II}_{ji}^D} \right)^{\rho_{II}} + (1 - \kappa_{ji}) \left(\frac{II_{ji}^M}{\bar{II}_{ji}^M} \right)^{\rho_{II}} \right]^{\frac{1}{\rho_{II}}} \tag{2.20}$$

In the IO table, three energy sectors (fuel, electricity and petroleum) are considered as energy inputs. I add up these three types of energy in this model, then aggregate with the imported energy inputs. An intermediate input to a sector i from a sector j is the aggregation of domestically produced and imported intermediate inputs. The degree of difference between domestic and imported inputs can be measured by a parameter such as the elasticity of substitution in the constant elasticity of substitution (CES) function. Smaller elasticities mean that the two goods are too different to substitute for each other. From equations (2.19) and (2.20), these elasticities of substitution between domestic and imported inputs are $\sigma_E = \frac{1}{1+\rho_E}$ for energy and $\sigma_{II}=\frac{1}{1+\rho_{II}}$ for intermediate inputs. These Armington elasticities for energy and intermediate inputs are equally assumed as 0.2 for the calibration, but this is changed in sensitivity analysis later. The final consumption of a sector i is also an Armington composition of domestic and imported goods.

$$FC_i = \left[\mu_i\left(\frac{FC_i^D}{\bar{FC}_i^D}\right)^\rho + (1-\mu_i)\left(\frac{FC_i^M}{\bar{FC}_i^M}\right)^\rho\right]^{\frac{1}{\rho}} \tag{2.21}$$

Again, I fix the elasticity of substitution between domestically produced and imported final consumption to be 0.2.

The output of each sector is assumed to transform into domestic use and export with constant elasticity of transformation (CET). The elasticity of transformation is $\eta=\frac{1}{1+\phi}$.

$$Y_i = \left(\theta_i DU_i^{\phi_i} + (1-\theta_i)EX_i^{\phi_i}\right)^{\frac{1}{\phi}}$$

I assume that the domestic use and export are perfectly substitutable each other, so I can rewrite the CET function above as a linear function.

$$Y_i = DU_i + EX_i \tag{2.22}$$

2.4.3 Calibration of the CGE Model

The parameters in the functions are decided by the reference quantity from the IO table. In fact, all reported information from the IO table is values of price × quantity. However, by setting all the prices at unity, then values in the IO table can be considered as quantity figures. Through the calibration, we can get the parameters in the CGE model. These parameters are fixed after the calibration. All parameters decided by the calibration are listed in Table 2.3. In equations (2.17) to (2.21), the parameters with a bar in the functional forms refer to the initial values from the data. I can obtain the changed value of prices and quantity caused by simulations of changes in the exogenous variables using the specified functions.

For simplicity, I assume that this economy is small enough that it does not have a significant

Table 2.3: Fixed Parameters after Calibration

Parameter	Meaning
α	Cost share of composition factor(α_{sr}, α_l and α_k)
β	Distribution between intermediate inputs and composite factor
δ	Distribution between energy and other inputs
γ	Expenditure share of consumption
λ	Distribution between domestic and imported energy inputs
κ	Distribution between domestic and imported intermediate inputs
μ	Distribution between domestic and imported final consumption

impact on the rest of the world. The point of the small economy assumption is that the export and import prices are exogenously given for this economy. To isolate and estimate the effect of Chinese import penetration on the U.S. energy use in the manufacturing sector by counter-factual simulations, all other factors are held constant.

2.4.4 General Equilibrium

A general equilibrium model considers the competitive behavior of each agent in the economy. Consumers earn income from wages and returns to capital and maximize their utility by demanding final goods. Producers use inputs and supply goods in the market. Production inputs are from consumers or other producers. Each sector producer is aiming to maximize profit.

The general equilibrium is defined by three conditions derived from solving the model: zero profit, market clearing and income balance. Zero profit conditions state that the cost of production and output tax equals value of output. For my model, the zero profit conditions should be satisfied for all production sectors, the final consumption sector and the trade sector. These conditions are associated with the level of each activity. The market clearing condition is that output equals intermediate use and final demands. In the model, all demanded final goods are equal to supplied goods, and the sum of the supplied factor should be equal to the factor demand in the market. The income balance condition states that the level of expenditure equals the value of the income of the consumer. Under these equilibrium conditions, the model is solved as a mixed complementarity problem (MCP) using the GAMS/MPSGE system described in Rutherford (1995).

Table 2.4: Scenarios related to increased imports from China and energy tax

	Description
a. Basic Scenario I	Increasing imports from China by price shock (10%)
b. Basic Scenario II	Energy tax in manufacturing (1%)
c. Combined Scenario	Increasing imports from China and energy use tax in manufacturing

2.5 Numerical Results

The purpose of this analysis is to try to isolate and estimate the effect of Chinese import penetration by counter-factual simulations. I introduce tax on energy use in the U.S. manufacturing sector in order to help understand the magnitude of the energy use response to increasing imports from China. Specifically, I examine what level of energy tax would offset this effect.

In Table 2.2, the selected values of elasticities of substitution for the basic simulation are reported.[14] Table 2.4 shows the simulation scenarios related to increased imports from China and energy tax in the U.S. The 'benchmark' columns in Tables 2.5 and 2.6 show the benchmark quantity from the IO table. Industry 7, 'Refined petroleum products and nuclear fuel' is not reported in the results because this industry is considered to be an energy sector, not a manufacturing sector.

For the first basic scenario, I consider the isolated effect of increasing imports from China due to a price shock. Because imports are endogenous, they respond to changing parameters for the price of these imports. All other world prices are held constant. Decreasing the relative imported price of goods produced by the Chinese manufacturing sector by about 10% for all manufacturing industries results in increased imports from China to the U.S. The results of this basic scenario of changes in energy use in the manufacturing sector are presented in Table 2.5. Energy use in all industries is increased proportionally as a result of the increased output of each industry. The changes in output are reported in Table 2.6. Specifically, industries in which the U.S. has a relative comparative advantage, such as in chemicals or machinery, increase their outputs and use energy more, while labor-intensive industries which have a high level of imports from China reduce their outputs and use less energy. With the calibration specifications, 10% of the price shock on imports from China leads to approximately a 0.58% increase in energy use and output in U.S. manufacturing.

[14]In sensitivity checks, these values are changed to convince the results.

Table 2.5: Changes in intermediate energy input by U.S. manufacturing

Sectors	Benchmark	Basic I	% △	Basic II	% △	Combined	% △
3	11447.898	11474.436	(0.232)	11335.586	(-0.981)	11361.842	(-0.752)
4	2134.940	2144.179	(0.433)	2106.009	(-1.355)	2115.150	(-0.927)
5	1471.028	1476.351	(0.362)	1454.615	(-1.116)	1459.886	(-0.757)
6	9709.872	9728.504	(0.192)	9626.411	(-0.860)	9644.856	(-0.670)
8	49800.213	50075.040	(0.552)	49429.389	(-0.745)	49701.310	(-0.199)
9	5840.354	5870.705	(0.520)	5776.091	(-1.100)	5806.114	(-0.586)
10	11145.230	11176.058	(0.277)	11021.067	(-1.114)	11051.481	(-0.841)
11	15472.037	15653.767	(1.175)	15249.678	(-1.437)	15428.744	(-0.280)
12	4929.398	4944.529	(0.307)	4871.063	(-1.183)	4886.053	(-0.879)
13	3305.038	3323.561	(0.560)	3264.258	(-1.234)	3282.587	(-0.679)
14	3615.331	3655.203	(1.103)	3575.238	(-1.109)	3614.691	(-0.018)
15	5513.878	5589.704	(1.375)	5419.935	(-1.704)	5494.610	(-0.349)
16	1814.079	1821.898	(0.431)	1789.766	(-1.340)	1797.510	(-0.913)
17	2318.413	2326.054	(0.330)	2294.107	(-1.048)	2301.678	(-0.722)
Total	128517.708	129259.990	(0.578)	127213.214	(-1.015)	127946.513	(-0.444)

The magnitude of the effect of increasing imports from China is very small.

The second basic scenario consider the energy tax only in the manufacturing sector. The column 'Basic II' of Table 2.5 shows changed energy use in each industry. 1% of the energy tax causes an increase in production cost; therefore, all industries produce less than the benchmark quantity. This is especially true of those industries that are highly energy-intensive, since they exhibit a more sensitive response to the energy tax and reduce output much more than other industries. With increasing imports from China, total energy use in the U.S. manufacturing sector is increased, as theory predicts. On the other hand, 1% of energy tax causes manufacturers to use less energy. This result is made obvious by the basic producer problems. Interestingly, manufacturers respond very sensitively to the energy tax such that only 1% of the energy tax reduces energy consumption by 1% while output decreases by 0.1%.

The last two columns of Tables 2.5 and 2.6 illustrate how energy use changes in the case of combining the two effects above. These show results with the same proportional increase in imports from China (10% of price shock) and 1% of the energy tax for all sectors. Combined, these two scenarios of increasing imports from China and the energy tax can produce an outcome consistent with the actual data: decreasing energy consumption with increasing output. Interestingly, total energy use in the manufacturing sector can decrease even as U.S. welfare increases due to its

Table 2.6: Changes in output by U.S. manufacturing

Sectors	Benchmark	Basic I		Basic II		Combined	
			% △		% △		% △
3	662198.908	663734.028	(0.232)	662259.323	(0.009)	663793.286	(0.241)
4	108567.065	109036.886	(0.433)	108166.815	(-0.369)	108636.304	(0.064)
5	111587.472	111991.221	(0.362)	111445.816	(-0.127)	111849.654	(0.235)
6	531117.804	532137.006	(0.192)	531818.168	(0.132)	532837.204	(0.324)
8	593141.040	596414.307	(0.552)	594611.589	(0.248)	597882.665	(0.799)
9	195858.452	196876.303	(0.520)	195640.433	(-0.111)	196657.306	(0.408)
10	113815.360	114130.301	(0.277)	113673.002	(-0.125)	113986.700	(0.151)
11	203253.382	205640.747	(1.175)	202335.621	(-0.452)	204711.511	(0.717)
12	284670.354	285544.164	(0.307)	284114.591	(-0.195)	284988.910	(0.112)
13	315536.828	317305.237	(0.560)	314759.894	(-0.246)	316527.339	(0.314)
14	452781.503	457774.986	(1.103)	452237.787	(-0.120)	457228.303	(0.982)
15	494721.674	501524.959	(1.375)	491155.709	(-0.721)	497922.714	(0.647)
16	189990.403	190809.368	(0.431)	189318.561	(-0.354)	190137.650	(0.078)
17	227122.748	227871.332	(0.330)	226989.025	(-0.059)	227738.187	(0.271)
Total	4484362.993	4510790.846	(0.589)	4478526.335	(-0.130)	4504897.732	(0.458)

improved terms of trade. That means that the energy tax can result in the benefits of trade liberalization and less anxiety over environmental problems associated with energy use. It bears a close relationship with what is occurring in the U.S. economy, which cannot be explained by traditional H-O theory. But even without an offsetting energy tax, the effect of an increase in Chinese import penetration on energy use in the manufacturing sector is estimated to be very small, as previously noted.

2.6 Sensitivity Checks

Figure 2.5 shows the changes in energy consumption and output due to increased imports from China depending on the tax rate. The benchmark has neither Chinese imports shock nor energy tax. 0% shows the results only of an increased imports from China as shown in the 'Basic I' columns in Tables 2.5 and 2.6. The remaining part of the graph shows how the energy tax offsets the increased energy consumption and output caused by Chinese import penetration. With specified functional forms, about 1% of the energy tax is fully offsetting the increased energy and keeping the increased output level. However, with the higher tax rate of about 5% in this figure, the output level becomes lower than the benchmark. This means that overly strict regulations lose the improved terms of trade in the U.S. even though energy use remains low.

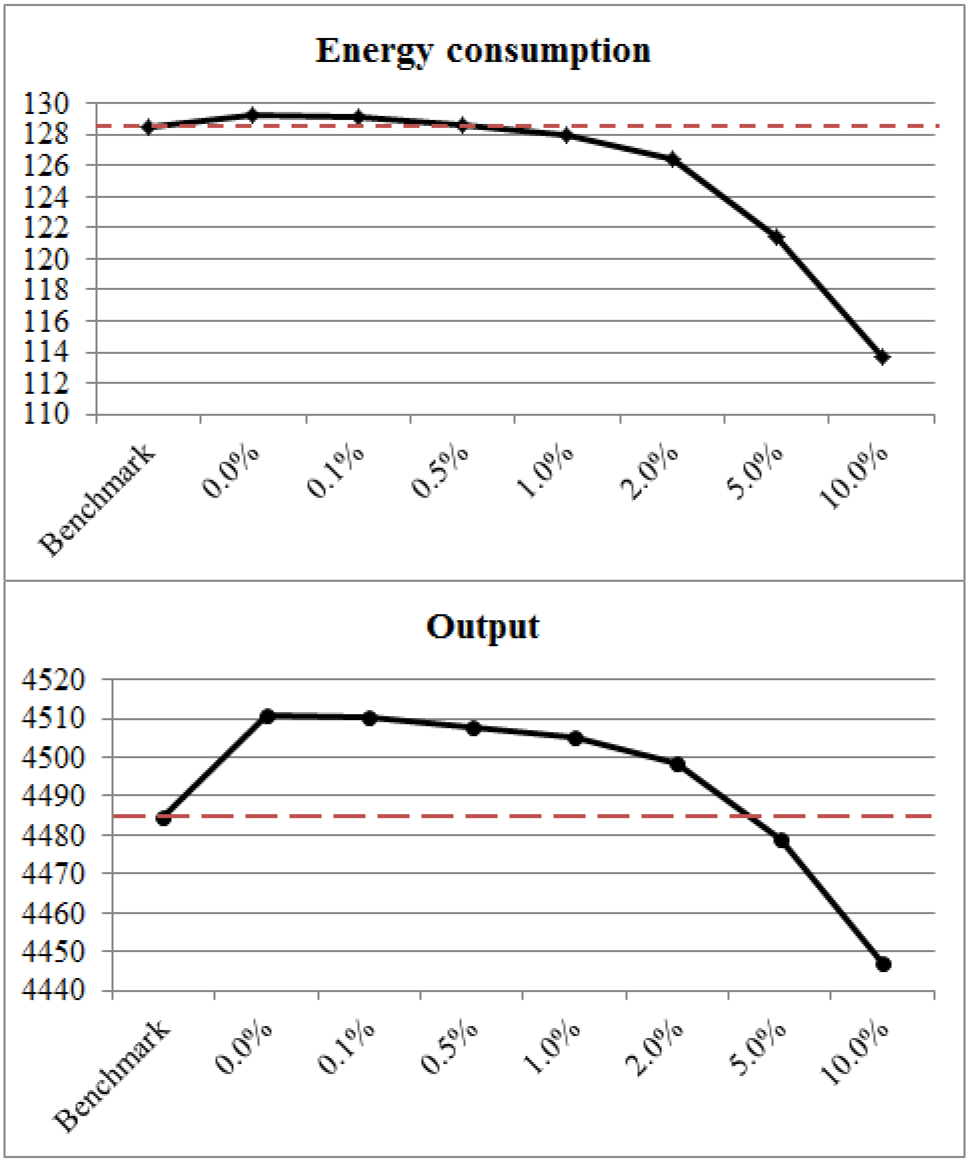


Figure 2.5: Changes depending on tax rate

Note: Except the benchmark, all results of taxes are based on increasing imports from China.

I also change the elasticities of substitution in the production function for sensitivity checks. For the baseline analysis, I choose both $\sigma 1$ and $\sigma 2$ to be equal to 0.5. I simulate the same scenarios with the production function which has less substitutability between factors and more substitutability between factors, respectively.[15] The results are reported in Figure 2.6. As factors are more substitutable, the effects of imports from China and energy tax are very vague. On the other hand, if factors are less likely to be substitutes, manufacturers respond to trade shock and energy tax more sensitively. Overall, except for the magnitude of the effect, the results are consistent with the baseline analysis.

2.7 Conclusion

Although imports from China continue to rise, total energy use in U.S. manufacturing continues to decline. This trend is inconsistent with the traditional factor endowment trade theory prediction. To find the determinants of energy consumption in U.S. manufacturing, I modify the Hechscher-Ohline model by adding energy tax in the North as a domestic regulation on energy use. This energy tax allows PHH to be included into the traditional H-O theory by revealing the preference of lowering energy use in the North, and causes the energy consumption in the North to be different from the traditional H-O model prediction. Without the energy tax, the North has a comparative advantage on energy-intensive industries and increases energy use as imports from the South increase. However, the energy tax can lead the North to use less energy because there will be a substitution both away from energy-intensive industries and away from energy use within industries. Increased imports from the South combined with the energy tax can result in the North using less energy than before and increasing welfare due to its improved terms of trade.

I conduct the CGE model of the U.S. economy using the U.S. input-output table for the base year 2005. I simulate several types of scenarios related to a Chinese import shock (due to a price shock) with or without an offsetting energy tax. This energy tax is introduced as a counter-factual to understand the magnitude of the effect of increasing Chinese imports. The numerical results show that increased imports from China cause all manufacturing industries in the U.S. to use more energy even though the magnitude of the effect is very small. However, the energy-decreasing effect

[15] I choose 0.3 and 0.8 for these sensitivity analyses.

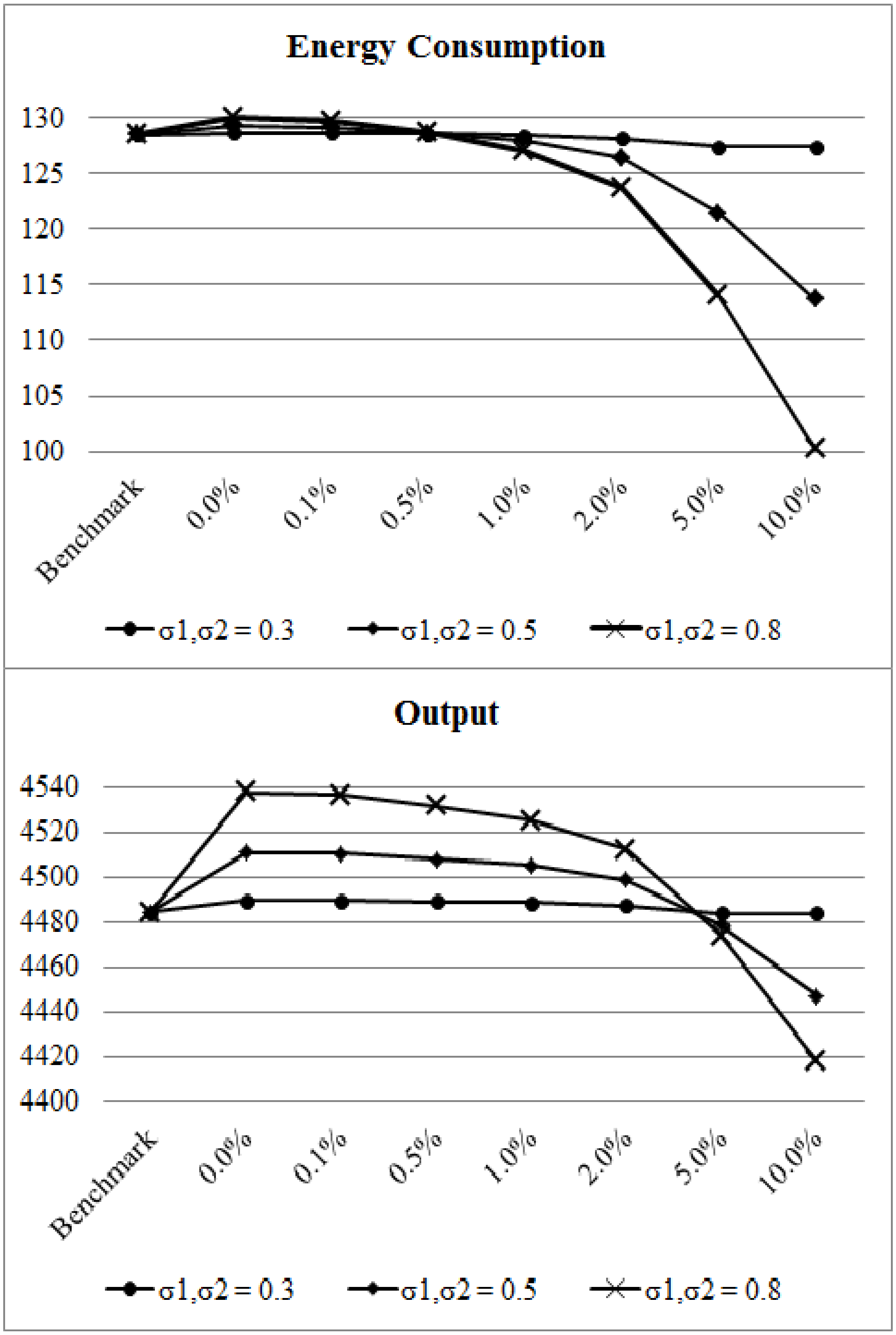


Figure 2.6: Changes depending on elasticities of substitution
Note: Except the benchmark, all results of taxes are based on increasing imports from China.

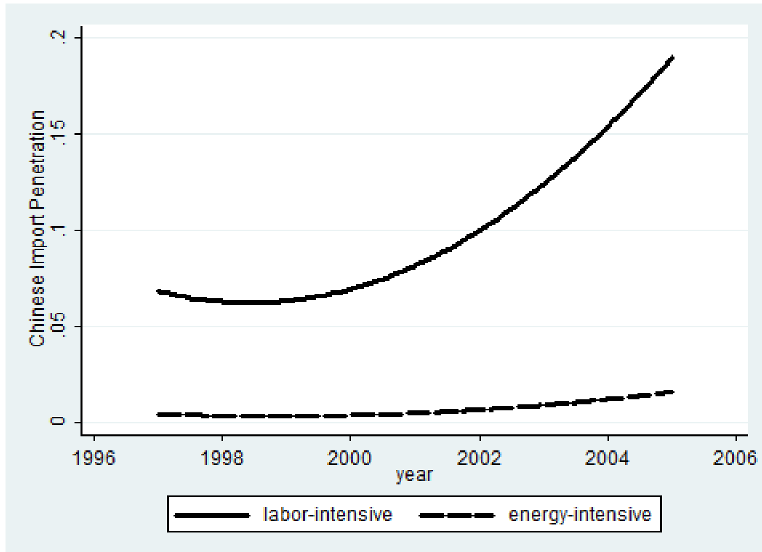
of an energy tax outweighs the energy-increasing effect of imports from China, while the positive welfare effect of trade still holds. However, even without an offsetting energy tax, the effect of an increase in Chinese import penetration on energy use in U.S. manufacturing is very small. Interestingly, total energy use in the U.S. manufacturing sector can decline, at the same time as U.S. welfare increases due to its improved terms of trade. This result indicates that a small energy tax can offset the increased energy use caused by Chinese import penetration, but will not reduce welfare. In addition, unlike the prediction of H-O theory, increasing Chinese imports also causes imported intermediate inputs from China to become cheaper and result in increasing outputs in all sectors of U.S. manufacturing.

CHAPTER III

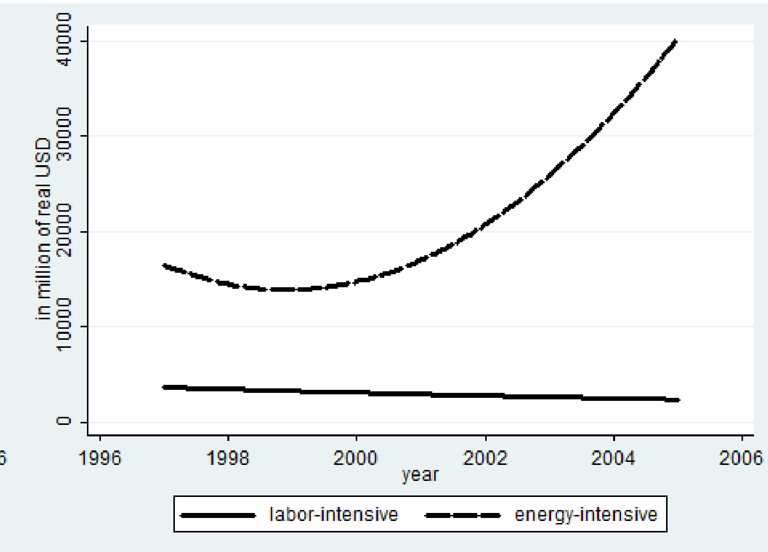
Energy Use in U.S. Manufacturing and Increasing Imports from China: Empirical Approach

3.1 Introduction

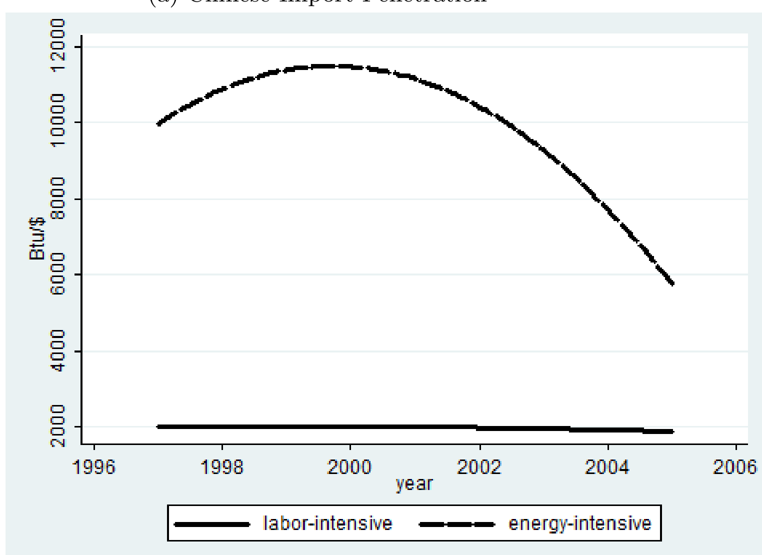
As discussed in the previous chapter, Heckscher-Ohlin (H-O) trade theory suggests that the structure of U.S. manufacturing should move toward more energy-intensive industries in response to increasing imports from China and as a result, energy use in U.S. industries should increase when Chinese import penetration is high. Specifically, labor-intensive industries face higher import penetration from China compared to energy-intensive industries. Faced with higher import penetration from China, labor-intensive industries in the U.S. should shrink and energy-intensive industries should expand, according to current theory. The graphs in Figure 3.1 show the difference between labor-intensive industries and energy intensive industries. Labor-intensive industries include textile and apparel, and energy intensive industries include petroleum and chemicals. Overall, Chinese exports to the U.S. are increased for both industries, but clearly labor-intensive industries face higher import penetration from China compared to energy intensive industries. The theory predicts that in the face of high import penetration from China, labor-intensive industries in the U.S. should shrink while energy-intensive industries expand. However, energy use in energy-intensive industries have not increased as much as outputs in those industries as the industries have grown over time. The graph of energy intensity shows clearly these changes.



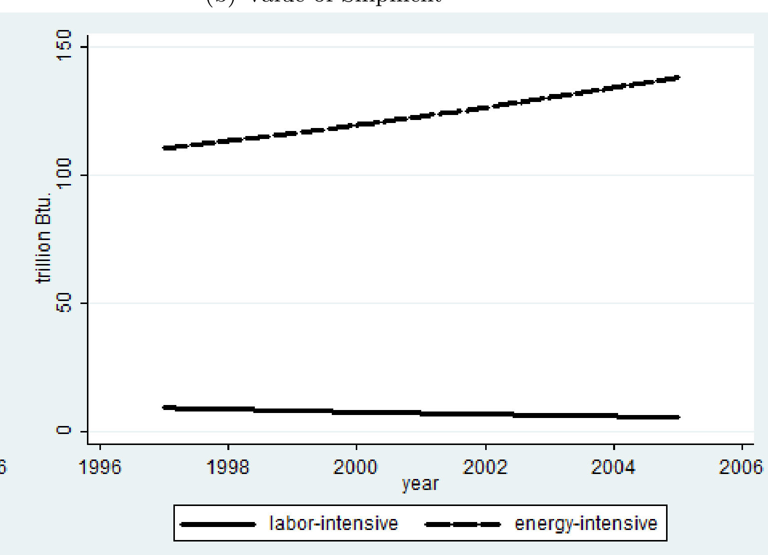
(a) Chinese Import Penetration



(b) Value of Shipment



(c) Energy intensity



(d) Quantity of Energy Use

Figure 3.1: US Manufacturing from 1997 to 2005

In this chapter, I numerically estimate the effect of increased Chinese import penetration using U.S. manufacturing industry-level panel data from 1997 to 2005. In addition, based on the empirical framework of Cole (2006), I also decompose the effect of increasing imports from China on energy use in U.S. manufacturing into an output scale effect and a factor substitution effect. Unlike Cole (2006), this paper focuses on the effect of increasing imports from China on the U.S. manufacturing sector, rather than the effect of general trade liberalization on national energy use. Because import penetration may have endogeneity problems, I instrument for Chinese import penetration using the Chinese share of world trade.

My empirical results indicate that overall, increasing imports from China raise consumption of fuel and electricity. As in CGE analysis, the marginal effect of Chinese import penetration is small, about 0.05% to 0.08%, but statistically significant. Interestingly, the directions of the factor substitution effects on fuel and electricity are opposite. Increasing imports from China causes a decrease in the factor ratio of fuel over labor, but an increase in electricity over labor.

3.2 Data

I construct a panel dataset by merging several datasets related to the US manufacturing industries for the years 1997 to 2005. My base datasets are the Annual Survey of Manufacturers (ASM) collected by the Census Bureau and the NBER's collection described in Schott (2010). The industry classification of the dataset is based on 1997 North American Industry Classification (NAICS) codes with 6 digits.

The first dataset, ASM, includes all characteristic variables on the manufacturing sector, divided into 473 industries by the NACIS 6-digit classification.[1] This data provides variables about energy use, such as the total cost of purchased fuel and the quantity of purchased electricity, as well as industrial characteristics such as output,[2] employment and capital expenditure. Additionally, I merge the data from the Statistics of US Businesses (SUSB), including the numbers of firms or establishments in each industry of manufacturing, into the previous dataset. This data is also

[1] This survey was also collected in previous periods. However, the survey was classified by SIC 4-digit classification instead of NAICS 6-digit classification before 1997. This prevents the use of a longer panel of data from earlier years.

[2] I use the value of shipment as a variable on output.

tabulated by industry classification based on NAICS codes with 6 digits.[3] It is difficult to examine exactly how existing firms change their decision about energy use based only on the data at the industrial level. Therefore, it is necessary to control for exit or entry effects caused by increasing competition by imports for each industry. The variable "number of firms in each industry" resolves the problem caused by the data limitation. This means that an increase in the number of firms implies that entry must have occurred, and a decrease in the number of firms implies an exit of firms from the industry.

The trade data for the US manufacturing sector comes from the NBER's collection described in Schott (2010). This is also constructed using the NAICS 6-digit classification, and among 473 sectors, there are 385 sectors that trade with other countries. These data are used to construct the key independent variable, Chinese import penetration, which is the ratio of manufacturing imports to total domestic supply for each industry.

$$\text{Chinese Import Penetration}(IP_{i,t}^{China}) = \frac{\text{Imports from China}}{\text{Domestic Output - Exports + Imports}} \tag{3.1}$$

3.2.1 Constructing Energy Price Index of US Manufacturing

A limitation of this dataset is that the actual quantities of used energy are not observed. The existing variables related to energy use include only the total cost of purchased energy,[4] the total cost of purchased fuel, and the quantity of purchased electricity. In fact, the quantity of energy use can be easily calculated given the energy price of each industry. Even though I cannot observe the energy price, I construct an energy price index to obtain the quantity of purchased energy (and fuel) in each industry using the given information. The energy price index is calculated by multiplying the average energy price in 1997 at the NAICS 3-digit classification to the energy deflator ($pien_{i,t}$)

[3] SUSB is collected annually by the U.S. Census Bureau. Even though SUSB has surveyed at NAICS 6-digit classification since 1998, the Economic Census contains the variable "number of firms and establishments" in 1997. By merging these two sources, I can construct the variable from 1997 to 2005 for the panel dataset.

[4] In this dataset, energy means the sum of fuel and electricity.

at the NAICS 6-digit classification for each year[5]. Using the estimated energy price of each industry ($\hat{P}^E_{i,t}$), the estimated quantity of energy is calculated by dividing the total cost of purchased energy ($TCE_{i,t}$) by the estimated energy price.

$$
\begin{aligned}
\hat{P}^E_{i,t} &= P^E_{z,1997} \cdot pien_{i,t} && z = \text{NAICS 3-digit} \\
\hat{Q}^{fuel}_{i,t} &= \frac{TCE_{i,t}}{\hat{P}^E_{i,t}} - Q^{elect}_{i,t} && i = \text{NAICS 6-digit}
\end{aligned} \tag{3.2}
$$

Figure 3.2 shows the comparison between the estimated average fuel price in manufacturing and the average fuel price for all industries from 1997 to 2005. The dashed line shows the average fuel price of all industries including agriculture, service, and manufacturing. The solid line is drawn to show the constructed energy price as described above, and it shows only the average estimated energy price for the U.S. manufacturing sector. Even though these lines are not comparing the price trends of the same range of industrial categories, the shape of the trend is very similar. These constructed variables of energy use are mainly utilized as dependent variables in the empirical analysis.

3.2.2 UN Comtrade Data

I also use the UN Comtrade database to construct an instrumental variable because Chinese import penetration is potentially endogenous.[6] UN Comtrade is an international database of 6-digit HS commodity level information on all bilateral imports and exports between any given pair of countries. I extract the bilateral exports from China to the world for the period and aggregate from the 6-digit HS commodity level to the 6-digit NAICS industry level using the concordance of Pierce and Schott (2009). I explain the instrumental variable in detail later.

[5] The average energy price in 1997 at NAICS 3-digit classification is from the manufacturing energy consumption survey (MECS) and the energy price deflator at NAICS 6-digit classification is included in the trade dataset of the NBER's collection.

[6] http://comtrade.un.org/db/

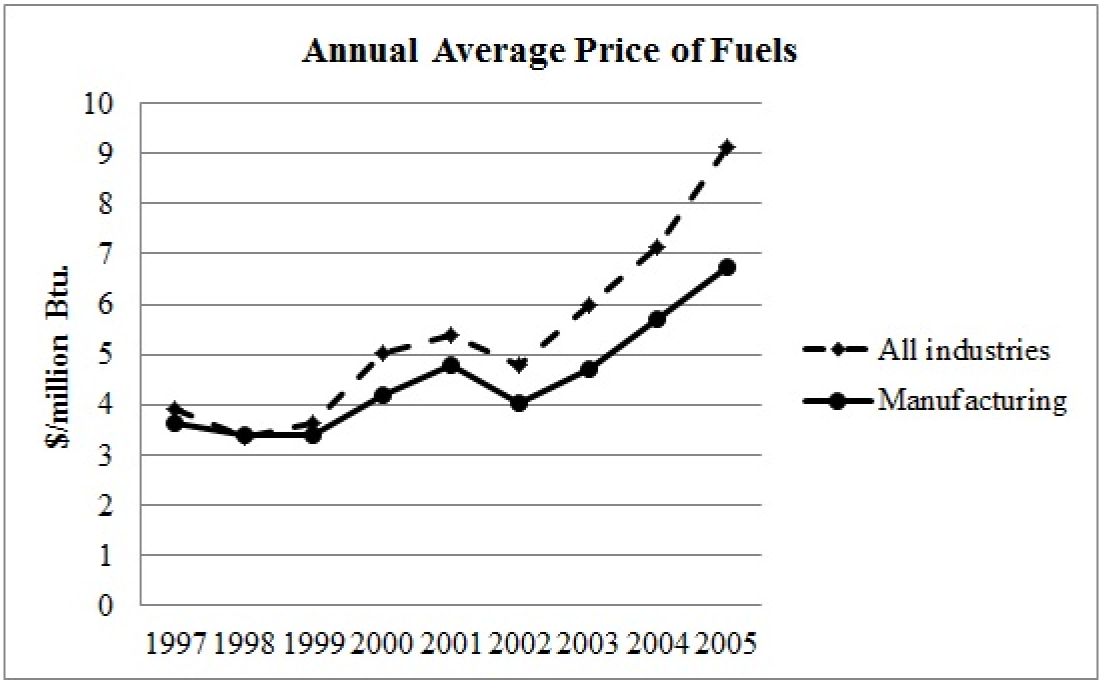


Figure 3.2: Comparison of energy price for all industries and energy price index for U.S. manufacturing

Note: The dashed line shows the annual average price of fuels for all industrial sectors including construction, agriculture as well as manufacturing sector. The solid line is calculated by the constructed energy price.

3.2.3 Descriptive Statistics

The descriptive statistics of the merged and conducted dataset is shown in Table 3.1. In the regression sample, I drop 36 industries which have negative or greater than 1 import penetration.[7] This gives me a sample of 3,465 trade observations among 4,257 industry observations in U.S. manufacturing for the period from 1997 to 2005.

The main independent variable, Chinese import penetration to the U.S. manufacturing sector, varies depending on industries. Traditional labor-intensive sectors such as textile and apparel have absolutely high penetration from China and the rate of their increase is also relatively high. Interestingly, Chinese import penetration to some sectors such as printing, chemicals, and machinery, rapidly increased during the period. The rate of increase of imports is even higher than traditional labor-intensive sectors. However, the absolute size of Chinese imports in these sectors is still very low.[8]

[7]By the definition of import penetration, this index cannot be negative or greater than 1.
[8]See Table A.1 in Appendix A.

Table 3.1: Summary statistics of U.S. manufacturing

Variable	Mean	Std. Dev.	Min.	Max.
Industrial Characteristics (N=4257)				
Value of shipment	8669.4	17143.7	98	445910
Employment	32.4	44.0	0.8	554.9
Payment	1235.0	1741.1	19.9	16162.9
Material Cost	4561.6	11678.0	34.8	345883.1
Value added	4122.4	7072.2	51.7	104711.5
Capital Expenditure	288.8	669.2	1.1	14583.6
Num. of firms	670.4	1593.6	3	23787
Industrial Trade (N=3465)				
Imports	2646.9	7145.7	0	126324.8
Exports	1730	4102.0	0	60005.5
Imports from low-wage countries	407.5	1145.0	0	19380.7
Imports from China	320.2	1035.3	0	18961.4
tariff	0.021	0.034	0	0.517
Variables related to Industrial Energy Use				
Total energy cost	158.9	482.4	0	11246.1
Total electric cost	86.4	188.1	0	2626.8
Total fuels cost	74.0	323.2	0	8619.4
Quantity of electricity (1000Kwh)	1782.2	4570.6	0	60552.5
Energy Price	8.654	3.1	2.4	16.1
Quantity of energy purchased (million Btu)	28.3	107.1	0.07	1760.7
Quantity of electric purchased (million Btu)	6.1	15.6	0	206.6
Quantity of fuels purchased (million Btu)	22.3	94.6	0.01	1607.4

Changes in energy use in U.S. manufacturing is interesting. Table A.2 shows how energy use of the manufacturing sector has changed depending on energy types. In the case of fuel, as imports from China have increased, the fuel consumption by those industries has decreased. Generally, these two variables move in opposite directions as theoretically predicted. However, in the case of electricity, those who have faced high import penetration from China also use more electricity. For example, NAICS 314 (textile product mills) has increased electricity use by 0.39%. In fact, this is similar to what is shown in the IO table.[9] Consumption distributions of electricity and fuel are very different across manufacturing industries. Fuel use is mostly concentrated in the industries, which are commonly considered to be energy-intensive industries, while electricity use is evenly distributed across all industries. These two points related to electricity demand in U.S. manufacturing suggest that electricity and fuel may be dealt with differently by manufacturers as a production factor.

3.3 Empirical Strategy

To examine how the determinants of energy use in the U.S. manufacturing sector respond to increasing imports from China, the empirical equation is specified as follows.[10]

$$E_{i,t} = \alpha_0 + \alpha_1 \cdot IP^{China}_{i,t} + \alpha_2 \cdot LK_{i,t} + \alpha_3 \cdot V.ship_{i,t} + \alpha_4 \cdot (V.ship)^2_{i,t} + \alpha_5 \cdot LK_{i,t}V.ship_{i,t} + \alpha_6 \cdot IP^{China}_{i,t}LK_{i,t} + \alpha_7 \cdot IP^{China}_{i,t}V.ship_{i,t} + \alpha_8 \cdot IP^{China}_{i,t}(LK)^2_{i,t} + \alpha_9 \cdot IP^{China}_{i,t}(V.ship)^2_{i,t} + \epsilon_{i,t} \quad (3.3)$$

The dependent variables ($E_{i,t}$) are variables about energy use in industry i at time t. $IP^{China}_{i,t}$ is the measure of import penetration from China, which is the ratio of imports from China to total US domestic supply for industry i at time t. LK is the ratio of payroll to capital expenditure. $V.ship$ is the value of the shipment, and its quadratic term is also included. For an alternative specification, total factor productivity (tfp) or the number of firms ($N.firm$) is included. The number of firms in each industry ($N_{i,t}$) helps control for the effect of exit and entry of firms by increasing competition induced by high import penetration. The error term ($\epsilon_{i,t}$) consists of industry fixed effect (θ_i), year fixed effect (ξ_t) and residual term ($\upsilon_{i,t}$). All variables are expressed in logarithms and the equation

[9] See Table 2.1.

[10] This specification is similar to Cole (2006), but it is different in that industry specific characteristics are considered.

is estimated using fixed effects to control for aggregate variation in energy use and unobservable industry characteristics.

As mentioned in the data description, there are potential endogeneity issues with estimating the equation (3.3). That is, if there is an unobserved shock that increases energy use among domestic firms in an industry, and imports from China are likely to fall, then this causes a downward bias of the estimated effect. There may be counter examples to show that unobserved shocks could raise energy use and attract more imports from China than other types of imports. To correct for this endogeneity problem, I construct an instrumental variable, the Chinese trade share of world trade, which is not correlated with unobserved shocks. The overall increase in Chinese exports is driven fundamentally by the country's opening to the global economy because of ongoing liberalization by policy makers. Therefore, it is arguably exogenous. The industries in which China has a comparative advantage are the ones that supply most of the Chinese exports. The U.S., one of the biggest trading partners with China, faces a disadvantage in its manufacturing industries due to increasing imports from China. Therefore, Chinese trade share of world trade could be used as an instrumental variable for import penetration from China into the U.S.[11] The Chinese trade share is the value of exports originating from China as a share of total world exports at the industry level.

As predicted in the simulation model, the marginal effect of increased imports from China is expected to be positive because the structure of the U.S. manufacturing sector would move toward more energy-intensive industries with comparative advantage compared to Chinese manufacturing. Through the decomposition of the trade effect, the factor substitution effect is expected to be negative because factor mobility through this trade with China causes more demand for labor in U.S. manufacturing, and the relative price of energy increases. More labor-intensive industries with high imports from China lead the industries to use less energy. The output scale effect is positive because more output requires more energy consumption as a production factor.

[11]This follows the "value share" approach outlined by Bernard et al. (2006)

Table 3.2: Estimation on the quantity of energy

	Fixed effects			Fixed effects with IV sample			IV Fixed effects		
MODEL	A	B	C	A	B	C	A	B	C
penCHN	0.0234	-0.188***	-0.808***	0.0233	-0.204***	-0.811***	0.108***	-0.00247	-0.136
	(0.0155)	(0.0512)	(0.210)	(0.0170)	(0.0516)	(0.218)	(0.0209)	(0.0739)	(0.233)
L/K	-0.107	-0.309	-0.405*	-0.157	-0.379	-0.460*	-0.200	-0.296*	-0.317*
	(0.251)	(0.257)	(0.241)	(0.256)	(0.261)	(0.244)	(0.161)	(0.168)	(0.167)
vship	1.456***	1.492***	2.261***	1.513***	1.541***	2.283***	1.469***	1.484***	1.635***
	(0.285)	(0.275)	(0.313)	(0.295)	(0.285)	(0.314)	(0.158)	(0.158)	(0.255)
sqvship	-0.0551***	-0.0495***	-0.0968***	-0.0582***	-0.0515***	-0.0973***	-0.0538***	-0.0511***	-0.0602***
	(0.0157)	(0.0154)	(0.0176)	(0.0163)	(0.0161)	(0.0176)	(0.00859)	(0.00857)	(0.0147)
LKvship	0.0312	0.0512*	0.0623**	0.0379	0.0599*	0.0694**	0.0427**	0.0522***	0.0547***
	(0.0300)	(0.0309)	(0.0286)	(0.0308)	(0.0315)	(0.0291)	(0.0180)	(0.0189)	(0.0191)
penCHNLK	0.0125	0.00333	0.000784	0.0120	0.00191	0.000154	0.0125	0.00801	0.00760
	(0.00795)	(0.00790)	(0.00787)	(0.00859)	(0.00840)	(0.00841)	(0.00856)	(0.00851)	(0.00834)
penCHNvship		0.0238***	0.173***		0.0257***	0.172***		0.0117	0.0424
		(0.00591)	(0.0475)		(0.00601)	(0.0498)		(0.00720)	(0.0496)
penCHNsqvship			-0.00885***			-0.00870***			-0.00177
			(0.00264)			(0.00276)			(0.00274)
Observations	3,313	3,313	3,313	3,206	3,206	3,206	3,204	3,204	3,204
R-squared	0.405	0.416	0.425	0.406	0.419	0.428	0.353	0.371	0.377
Number of NAICS	380	380	380	365	365	365	363	363	363
Marginal Effects									
penCHN	0.0108	0.0089	0.0055	0.0110	0.0094	0.0066	0.0956***	0.0876***	0.0854***
	(0.0099)	(0.0101)	(0.0010)	(0.0106)	(0.0107)	(0.0107)	(0.0190)	(0.0204)	(0.0211)
penCHNLK	0.0125	0.0033	0.0008	0.0120	0.0019	0.0002	0.0125	0.0080	0.0076
	(0.0076)	(0.0079)	(0.0079)	(0.0086)	(0.0084)	(0.0084)	(0.0086)	(0.0085)	(0.0083)
penCHNvship		0.0238***	0.0984***		0.0256***	0.0988***		0.0117	0.0275
		(0.0059)	(0.0256)		(0.0060)	(0.0268)		(0.0072)	(0.0270)

Note: All specifications include time-fixed effects with robust standard errors. All variables are in logarithm. Elasticities are evaluated at sample means using the Delta method. *** < 0.01, ** < 0.05, * < 0.1

3.4 Empirical Results

The first three columns of Table 3.2 show the results of basic specifications with the pooled OLS. All specifications include year and industry fixed effects to control for industry-specific macro shocks and time-invariant unobserved variables. In addition, the standard errors are corrected by robust estimators.[12] The quantity of purchased energy is used as the dependent variable. Because of the interaction terms, the coefficient of Chinese import penetration ('penCHN') itself does not explain the trade effect. To examine the trade effect, I calculate the marginal effect at the sample mean. The marginal effect of increasing imports from China is positive at all specifications, but these are statistically insignificant in the pooled OLS estimation.[13] The results also show that the trade effect is positive, but statistically insignificant. Unlike the theoretical prediction of the factor substitution effect, the results indicate that such industries facing higher import penetration from China use more energy. However, the marginal effects of factor substitution and output scale effect are both insignificant.

The last three columns in Table 3.2 show the results of the instrumental variable (IV) regression. In the results of the IV estimation, the marginal effect of an increased imports penetration from China is positive and statistically significant. This means that 1% of increased imports from China increase energy use by about 0.08% to 0.09% in the U.S.[14] This is consistent with the theoretical prediction and the simulation results in the previous section. These results indicate that the structure of US manufacturing has a comparative advantage against Chinese imports and moves toward more energy-intensive industries. In terms of the factor substitution effect, the IV estimation also does not show the negative effect as predicted. I examine this effect more carefully by separating the dependent variable by energy types in the next section.

The three columns in the middle of Table 3.2 show the results of the pooled OLS with the sample of IV regression. These results support that the IV results do not result in the changes in the sample of regression. These results are not different from the results of the pooled OLS with

[12]In the case of the specifications 'Fixed effects' and 'Fixed effects with IV sample', the regressions with clustering in the NAICS 6-digit give the same results. However, the IV regressions with clustering in the NAICS 6-digit give the different results from the regressions with robust. For IV fixed-effects estimation with cluster, it makes no degrees-of-freedom adjustment for the number of fixed effects. Without the adjustment, I cannot calculate the same standard errors as in the robust case. See Wooldridge (2002).

[13]These results without the interaction terms are shown in Appendix C.

[14]All specifications show similar results. The results of all specifications are reported in Appendix B.

the full sample.[15]

3.5 Robustness Checks

3.5.1 Fuel vs. Electricity

Tables 3.3 and 3.4 show the results by energy type: fuel versus electricity. As mentioned in the section on descriptive statistics, fuel and electricity seem to have different demand patterns in the U.S. manufacturing sector. Therefore, this separation of the dependent variable is quite reasonable to examine. In the case of fuel, the results strongly support the theoretical prediction. The trade effect on fuel is positive, while the factor substitution effect is negative. This implies that increasing imports from China cause overall fuel consumption by the U.S. manufacturing sector to rise, but labor-intensive industries in this situation use less fuel. Specifically, all results by IV estimation are statistically significant. IV estimates show that the marginal effect of Chinese import penetration ranges from 0.05 to 0.07, and the factor substitution effect is about -0.02. In addition, higher output associated with import penetration from China leads to more fuel use. That is, the industries with comparative advantages against China expand their production more, resulting in more fuel consumption.

In the case of electricity, the result of the trade effect is consistent with the previous results: more imports from China also increase electricity demand by U.S. manufacturers. However, the direction of the factor substitution effect is the opposite of the theoretical prediction. These results indicate that labor-intensive industries with high Chinese import penetration use more electricity. This is the opposite of the result of fuel consumption. The IV estimates are shown in the last three columns in Table 3.4, in which all results are more significant than the pooled OLS estimates. The coefficient is approximately 0.03 for all specifications. This suggests that electricity could have the potential to easily replace labor. Therefore, labor-intensive industries use more electricity, thus reducing labor. Further research could investigate the substitutability of non-energy inputs such as labor and capital, with each energy type.

[15]The difference in number of observations between the specifications of 'Fixed effects with IV sample' and 'IV Fixed effects' is caused by two singleton observations. These two observations are automatically dropped in the 'IV Fixed effects regression'.

Table 3.3: Estimation on the quantity of fuel

	Fixed effects			Fixed effects with IV sample			IV Fixed effects		
MODEL	A	B	C	A	B	C	A	B	C
penCHN	0.00302	-0.226***	-1.054***	0.00402	-0.245***	-1.059***	0.0571***	-0.0879	-0.478**
	(0.0162)	(0.0553)	(0.2270)	(0.0176)	(0.0564)	(0.233)	(0.0212)	(0.0754)	(0.2350)
L/K	0.0636	-0.160	-0.292	0.0238	-0.224	-0.338	-0.118	-0.245	-0.308
	(0.3180)	(0.3260)	(0.2980)	(0.329)	(0.337)	(0.307)	(0.1920)	(0.2010)	(0.1990)
vship	1.526***	1.566***	2.594***	1.585***	1.615***	2.611***	1.620***	1.640***	2.081***
	(0.2940)	(0.2890)	(0.3560)	(0.307)	(0.302)	(0.357)	(0.1740)	(0.1760)	(0.2830)
sqvship	-0.0593***	-0.0532***	-0.116***	-0.0626***	-0.0553***	-0.117***	-0.0621***	-0.0585***	-0.0850***
	(0.0163)	(0.0163)	(0.0213)	(0.0170)	(0.0171)	(0.0214)	(0.0095)	(0.0095)	(0.0162)
LKvship	0.00158	0.0237	0.0392	0.00767	0.0322	0.0456	0.0169	0.0296	0.0372*
	(0.0387)	(0.0398)	(0.0362)	(0.0400)	(0.0411)	(0.0373)	(0.0211)	(0.0220)	(0.0218)
penCHNLK	-0.00408	-0.0140*	-0.0174**	-0.00427	-0.0152*	-0.0177**	-0.0154	-0.0211**	-0.0222**
	(0.0085)	(0.0082)	(0.0083)	(0.00917)	(0.00878)	(0.00893)	(0.0096)	(0.0096)	(0.0096)
penCHNvship		0.0258***	0.225***		0.0281***	0.224***		0.0153**	0.105**
		(0.0064)	(0.0522)		(0.00651)	(0.0538)		(0.0074)	(0.0498)
penCHNsqvship			-0.0118***			-0.0117***			-0.00517*
			(0.0030)			(0.00306)			(0.0027)
Observations	3,296	3,296	3,296	3,189	3,189	3,189	3,187	3,187	3,187
R-squared	0.425	0.435	0.447	0.424	0.435	0.448	0.396	0.412	0.425
Number of NAICS	380	380	380	365	365	365	363	363	363
Marginal Effects									
penCHN	0.0071	0.0052	0.0006	0.0084	0.0068	0.0029	0.0727***	0.0621***	0.0557**
	(0.0105)	(0.0105)	(0.0104)	(0.0111)	(0.0112)	(0.0111)	(0.0207)	(0.0220)	(0.0222)
penCHNLK	-0.0041	-0.0140*	-0.0174**	-0.0043	-0.0152*	-0.0177**	-0.0154	-0.0211**	-0.0222**
	(0.0085)	(0.0082)	(0.0083)	(0.0092)	(0.0088)	(0.0089)	(0.0096)	(0.0096)	(0.0096)
penCHNvship		0.0258***	0.1254***		0.0281***	0.1262***		0.0153**	0.0616**
		(0.0064)	(0.0274)		(0.0065)	(0.0284)		(0.0074)	(0.0273)

Note: All specifications include time-fixed effects with robust standard errors. All variables are in logarithm. Elasticities are evaluated at sample means using the Delta method. *** < 0.01, ** < 0.05, * < 0.1

Table 3.4: Estimation on the quantity of electricity

	Fixed effects			Fixed effects with IV sample			IV Fixed effects		
MODEL	A	B	C	A	B	C	A	B	C
penCHN	0.0360**	-0.0866	-0.296	0.0338*	-0.0924*	-0.293	0.109***	0.121	0.488*
	(0.0167)	(0.0614)	(0.2660)	(0.0180)	(0.0526)	(0.275)	(0.0243)	(0.0882)	(0.2850)
L/K	-0.348	-0.467*	-0.501*	-0.413*	-0.539**	-0.567**	-0.371**	-0.360*	-0.301
	(0.2480)	(0.2560)	(0.2650)	(0.249)	(0.219)	(0.267)	(0.1820)	(0.1980)	(0.2080)
vship	1.512***	1.533***	1.793***	1.564***	1.580***	1.825***	1.482***	1.480***	1.066***
	(0.2900)	(0.2830)	(0.3750)	(0.296)	(0.314)	(0.376)	(0.1600)	(0.1620)	(0.3260)
sqvship	-0.0590***	-0.0557***	-0.0717***	-0.0614***	-0.0576***	-0.0727***	-0.0560***	-0.0563***	-0.0314*
	(0.0154)	(0.0153)	(0.0204)	(0.0158)	(0.0181)	(0.0205)	(0.0084)	(0.0082)	(0.0185)
LKvship	0.0714***	0.0832***	0.0871***	0.0792***	0.0917***	0.0950***	0.0791***	0.0781***	0.0709***
	(0.0269)	(0.0276)	(0.0286)	(0.0272)	(0.0284)	(0.0288)	(0.0196)	(0.0212)	(0.0226)
penCHNLK	0.0260***	0.0207**	0.0198**	0.0245**	0.0190*	0.0184*	0.0331***	0.0336***	0.0347***
	(0.0092)	(0.0095)	(0.0095)	(0.00971)	(0.00977)	(0.00999)	(0.0097)	(0.0101)	(0.0103)
penCHNvship		0.0138**	0.0642		0.0142**	0.0626		-0.00131	-0.0857
		(0.0070)	(0.0600)		(0.00635)	(0.0624)		(0.0082)	(0.0599)
penCHNsqvship			-0.00299			-0.00287			0.00486
			(0.0033)			(0.00345)			(0.0033)
Observations	3,296	3,296	3,296	3,189	3,189	3,189	3,187	3,187	3,187
R-squared	0.339	0.342	0.343	0.350	0.350	0.350	0.316	0.314	0.303
Number of NAICS	380	380	380	365	365	365	363	363	363
Marginal Effects									
penCHN	0.0098	0.0088	0.0077	0.0089	0.0081	0.0071	0.0751***	0.0760**	0.0821**
	(0.0111)	(0.0116)	(0.0115)	(0.0119)	(0.0121)	(0.0119)	(0.0224)	(0.0250)	(0.0265)
penCHNLK	0.0260***	0.0207**	0.0198**	0.0245**	0.0190*	0.0184*	0.0331***	0.0336***	0.0347***
	(0.0092)	(0.0095)	(0.0095)	(0.0097)	(0.0100)	(0.0100)	(0.0097)	(0.0101)	(0.0103)
penCHNvship		0.0138**	0.0390		0.0142**	0.0384		-0.0013	-0.0449
		(0.0070)	(0.0323)		(0.0072)	(0.0337)		(0.0082)	(0.0326)

Note: All specifications include time-fixed effects with robust standard errors. All variables are in logarithm. Elasticities are evaluated at sample means using the Delta method. *** < 0.01, ** < 0.05, * < 0.1

3.5.2 Exit and Entry

Increasing imports from China possibly causes domestic firms to face higher competition. It is possible that this competition causes the domestic firms to exit the market. Therefore, it is necessary to control for this effect. Because of the limitation of the industry level data, how each firm responds to this increase in competition is not observable. Instead, I control for the number of firms in each industry. The IV regression results from adding the number of firms are reported in Table C.4 for fuel and C.6 for electricity. Since the coefficient of the number of firms on fuel is significantly positive, this means that the industries in which entry of firms occurs use more energy. As a result of controlling for the number of firms, the calculated marginal effect of Chinese import penetration is slightly larger. The magnitude of the factor substitution effect of fuel also increases to -0.048. However, for electricity, the number of firms does not significantly affect the electricity demand.

3.6 Conclusion

In this chapter, I numerically estimate the effect of increasing imports from China using U.S. manufacturing industry level panel data from 1997 to 2005. Since import penetration is potentially endogenous, I instrument using the Chinese trade share of world trade for Chinese import penetration to U.S. manufacturing. As shown in the previous chapter, my empirical results of IV estimation also show the overall positive trade effect of increasing imports from China on consumption of fuel and electricity. The marginal effect of Chinese import penetration is small, at about 0.05% to 0.08%, but is statistically very significant.

The effect of increasing imports from China is also decomposed into an effect on factor use and an effect on output. The interesting finding from the decomposition of the trade effect is that the factor substitution effect and output scale effect have the opposite effect on consumption of fuel and electricity. In the case of fuel, the factor substitution effect is negative and the output scale effect is positive. This means that increasing imports from China decrease the ratio of labor over fuel within industries, and as output increases due to increased Chinese import penetration, the industries use more fuel. This result is consistent with the prediction of traditional trade theory. However, the opposite results are shown in the case of electricity. The factor substitution effect on electricity is positive which means that electricity is considered to be substitutable with labor rather than fuel.

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APPENDIX A

Chinese Import Penetration and Energy Use in U.S. Manufacturing

Table A.1: Import Penetration from China into U.S. manufacturing, 1997-2005

		Chinese Import Penetration			
	NAICS			Changes	
Sectoral Description	code	1997	2005	2005-1997	%
Food	311	0.002	0.006	0.004	1.90
Beverage and Tobacco Product	312	0.000	0.000	0.000	0.62
Textile Mills	313	0.006	0.075	0.070	12.11
Textile Product Mills	314	0.027	0.123	0.096	3.61
Apparel	315	0.115	0.286	0.171	1.48
Leather and Allied Product	316	0.306	0.511	0.205	0.67
Wood Product	321	0.007	0.027	0.019	2.68
Paper	322	0.019	0.039	0.020	1.03
Printing and Related Support Activities	323	0.023	0.117	0.094	4.13
Petroleum and Coal Products	324	0.000	0.000	0.000	0.63
Chemical	325	0.004	0.018	0.014	3.54
Plastics and Rubber Products	326	0.006	0.023	0.017	2.98
Nonmetalic Mineral Product	327	0.017	0.048	0.031	1.89
Primary Metal	331	0.006	0.021	0.015	2.37
Fabricated Metal Product	332	0.011	0.051	0.039	3.52
Machinery	333	0.013	0.062	0.049	3.78
Computer and Electronic Product	334	0.029	0.124	0.094	3.25
Electrical Equipment, Appliance, and Component	335	0.048	0.129	0.081	1.67
Transportation Equipment	336	0.004	0.013	0.009	2.33
Furniture and Related Product	337	0.030	0.128	0.097	3.22
Miscellaneous	339	0.100	0.194	0.094	0.94
All sectors		0.030	0.082	0.052	1.70

Table A.2: Changes in Energy Use in U.S. Manufacturing, by sectors 1997-2005

	Quantity of Purchased Fuels				Quantity of Purchased Electricity			
			Changes				Changes	
NAICS	1997	2005	2005-1997	%	1997	2005	2005-1997	%
311	16.581	18.926	2.345	0.14	4.115	5.722	1.607	0.39
312	9.587	9.987	0.400	0.04	2.900	3.550	0.650	0.22
313	14.061	9.144	-4.917	-0.35	8.109	6.172	-1.938	-0.24
314	4.438	3.864	-0.574	-0.13	2.031	2.825	0.794	0.39
315	1.802	0.497	-1.305	-0.72	1.003	0.495	-0.508	-0.51
316	0.694	0.385	-0.309	-0.45	0.320	0.325	0.005	0.01
321	9.748	10.189	0.440	0.05	5.328	6.817	1.489	0.28
322	66.552	62.218	-4.334	-0.07	11.951	12.862	0.911	0.08
323	3.703	3.173	-0.531	-0.14	4.062	5.166	1.103	0.27
324	227.241	350.000	122.759	0.54	27.287	33.552	6.265	0.23
325	70.779	92.387	21.608	0.31	15.764	15.116	-0.648	-0.04
326	8.834	9.206	0.372	0.04	10.010	13.173	3.162	0.32
327	35.806	40.099	4.293	0.12	5.349	6.595	1.246	0.23
331	56.510	79.591	23.081	0.41	17.402	17.923	0.522	0.03
332	5.873	4.871	-1.002	-0.17	3.294	4.201	0.907	0.28
333	2.302	1.782	-0.520	-0.23	1.876	2.115	0.238	0.13
334	2.899	2.206	-0.693	-0.24	4.300	3.936	-0.363	-0.08
335	18.743	16.417	-2.326	-0.12	2.549	2.494	-0.055	-0.02
336	9.380	7.910	-1.470	-0.16	6.050	6.592	0.542	0.09
337	2.528	1.920	-0.608	-0.24	2.207	2.601	0.393	0.18
339	1.762	1.511	-0.251	-0.14	1.401	1.874	0.473	0.34
All	20.936	24.692	3.757	0.18	5.938	6.552	0.614	0.10

Table A.3: Energy Use, Output and Energy Intensity by U.S. manufacturing

NAICS	Description	Consumption of energy			Value of Shipment			Energy Intensity		
		1998	2002	2006	1998	2002	2006	1998	2002	2006
311	Food	1,044.0	1,123.0	1,186.0	430.5	447.9	472.0	2.425	2.507	2.513
312	Beverage and Tabacco Products	108.0	105.0	107.0	121.2	96.1	109.0	0.891	1.093	0.982
313	Textile Mills	256.0	207.0	178.0	55.6	46.8	37.2	4.608	4.428	4.779
314	Textile Product Mills	50.0	60.0	72.0	31.2	31.5	30.1	1.601	1.903	2.395
315	Apparel	48.0	30.0	14.0	65.4	44.8	29.9	0.734	0.670	0.469
316	Leather and Allied Products	8.0	7.0	3.0	10.3	6.4	5.6	0.775	1.093	0.540
321	Wood Products	509.0	377.0	451.0	91.8	89.5	99.6	5.546	4.214	4.529
322	Paper	2,747.0	2,363.0	2,354.0	167.5	155.9	153.0	16.396	15.160	15.381
323	Printing and Related Support	98.0	98.0	85.0	103.2	92.9	92.4	0.950	1.055	0.920
324	Petroleum and Coal Products	7,320.0	6,799.0	6,864.0	227.5	242.0	265.4	32.182	28.098	25.866
325	Chemicals	6,064.0	6,465.0	5,149.0	439.5	451.6	509.4	13.796	14.314	10.107
326	Plastics and Rubber Products	328.0	351.0	337.0	167.9	170.9	175.1	1.953	2.054	1.925
327	Nonmetallic Mineral Products	979.0	1,059.0	1,114.0	96.5	93.2	102.4	10.140	11.357	10.877
331	Primary Metals	2,560.0	2,120.0	1,736.0	164.8	144.6	160.0	15.534	14.657	10.849
332	Fabricated Metal Products	445.0	388.0	396.0	257.5	245.6	263.7	1.728	1.580	1.502
333	Machinery	217.0	177.0	204.0	285.3	247.7	291.8	0.761	0.715	0.699
334	Computer and Electronic Products	205.0	201.0	142.0	352.7	437.4	605.3	0.581	0.460	0.235
335	Electrical Equip., Appliances and Components	143.0	172.0	103.0	116.7	104.9	104.3	1.225	1.640	0.987
336	Transportation Equipment	492.0	429.0	477.0	621.4	638.6	668.5	0.792	0.672	0.714
337	Furniture and Related Products	88.0	64.0	61.0	71.5	74.0	76.7	1.230	0.865	0.795
339	Miscellaneous	89.0	71.0	66.0	107.1	122.0	135.3	0.831	0.582	0.488
	Total	23,796.0	22,666.0	21,098.0	3,985	3,984	4,387			

APPENDIX B

The U.S. Input-Output Table in 2005

Table B.1: Descriptions of Columns and Rows in I-O Table

	Rows		Columns
1	Mining and quarrying	1	Mining and quarrying
2	Electricity, gas and water supply	2	Electricity, gas and water supply
3	Food products, beverages and tobacco	3	Food products, beverages and tobacco
4	Textiles, textile products leather and footwear	4	Textiles, textile products leather and footwear
5	Wood and products of wood and cork	5	Wood and products of wood and cork
6	Pulp, paper, paper products, printing and publishing	6	Pulp, paper, paper products, printing and publishing
7	Coke, refined petroleum products and nuclear fuel	7	Coke, refined petroleum products and nuclear fuel
8	Chemicals and chemical products	8	Chemicals and chemical products
9	Rubber and plastics products	9	Rubber and plastics products
10	Other non-metallic mineral products	10	Other non-metallic mineral products
11	Basic metals	11	Basic metals
12	Fabricated metal products except machinery and equipment	12	Fabricated metal products except machinery and equipment
13	Machinery and equipment n.e.c	13	Machinery and equipment n.e.c
14	Electrical and optical equipment	14	Electrical and optical equipment
15	Motor vehicles, trailers and semi-trailers	15	Motor vehicles, trailers and semi-trailers
16	Other transport equipment	16	Other transport equipment
17	Manufacturing n.e.c; recycling	17	Manufacturing n.e.c; recycling
18	Other industries	18	Other industries
19	Gross Operating Surplus	19	Household consumption
20	Compensation of Employees	20	Government spending
21	Taxes less subsidies on production	21	Gross fixed capital formation
		22	Changes in inventories
	Columns (with import tax)	23	Export
27	Imported intermediate inputs from China	24	Import from China
28	Imported intermediate inputs from rest of world	25	Import from rest of world
29	Total imported intermediate inputs	26	Import tax
30	Imported final consumption from China		
31	Imported final consumption from rest of world		
32	Total imported final consumption		

Table B.2: Domestic/Imported Intermediate Use Matrix, Value Added and Tax (Subsidy)

Domestic Intermediate Use Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Subtotal
1	32881.7	64624.4	527.7	91.2	39.6	874.3	132229.0	9625.0	245.4	7115.1	8017.5	247.9	197.5	337.1	2443.8	71.3	265.9	30781.3	290615.8
2	3336.4	3898.9	8623.7	1248.7	868.5	5057.5	6723.5	7757.0	2421.5	2945.7	3785.6	2970.4	1647.3	2365.3	1715.0	784.9	1324.7	174248.4	231723.0
3	56.6	12.0	88618.6	956.0	61.5	964.1	296.6	2767.0	352.7	46.7	79.4	89.8	115.5	200.4	168.9	73.8	449.8	142634.6	237943.9
4	56.7	14.2	320.3	19643.2	117.4	2604.0	65.6	799.1	3196.9	154.4	42.9	146.4	495.1	167.0	5704.1	914.4	6498.6	14911.7	55851.9
5	82.7	363.3	608.6	212.0	18707.7	2312.7	77.7	364.0	214.2	316.8	249.4	312.0	540.2	345.4	809.6	311.8	8155.4	64372.6	98356.1
6	1169.8	545.8	20181.4	1113.5	642.0	76822.6	1510.2	9036.2	3714.0	1702.2	681.3	2164.0	2584.4	12428.8	2953.1	1052.1	4798.2	191238.1	334337.8
7	8742.4	4630.5	1699.0	715.1	435.7	2793.8	30226.4	21853.2	2839.8	564.8	2021.1	1379.5	1179.6	751.8	1043.2	765.8	595.6	171006.9	253244.3
8	4720.4	389.9	5148.2	10302.4	1215.8	9671.2	6254.1	106184.3	40795.7	2226.6	1369.9	3754.5	3151.2	6599.2	5632.3	2346.2	5182.0	109528.2	324472.4
9	1229.3	569.4	13848.9	599.0	608.0	3809.2	536.9	9907.4	9945.3	776.3	266.1	1297.3	5964.9	4825.6	11867.8	2381.2	7611.8	83842.7	159887.1
10	1461.7	854.0	3228.3	166.6	699.8	237.3	1209.4	1337.7	936.1	9689.4	1958.8	835.4	1251.4	1069.3	3375.0	619.3	810.7	73248.9	102989.3
11	3453.2	490.3	116.5	20.3	34.9	512.7	61.3	446.1	919.5	688.0	39188.8	40047.5	24357.4	11294.3	27194.0	6291.4	5979.7	15491.5	176587.3
12	4126.6	1250.4	10263.5	493.1	1741.2	3629.7	1695.2	5182.2	2185.3	1177.5	3881.1	24463.6	23200.4	12138.2	22552.3	12911.1	6369.6	102025.9	239286.7
13	4172.7	238.2	1024.3	205.4	200.7	1304.2	179.2	1572.3	1043.9	147.1	1302.2	2295.4	14979.9	3011.1	12545.1	3506.4	962.4	38108.0	86798.6
14	378.3	1062.6	1177.5	489.4	607.3	3895.6	623.5	2634.0	1483.3	508.1	2232.3	2316.1	9723.9	41107.1	8869.7	9948.4	2078.5	71242.5	160378.3
15	796.4	79.5	315.2	399.9	174.5	245.6	128.0	192.8	105.5	89.3	90.7	310.8	3114.3	427.4	107148.5	1171.2	242.8	54008.7	169041.2
16	63.6	10.2	54.7	15.8	9.6	56.3	18.1	45.0	19.7	5.2	24.3	59.4	223.9	115.1	312.5	14495.5	32.4	33613.8	49175.2
17	173.7	78.2	627.1	342.3	2189.9	520.4	149.5	913.9	345.4	165.8	185.3	367.4	784.8	1158.1	839.7	435.3	6446.2	54530.2	70253.2
18	75405.6	47320.8	326697.8	23037.2	34614.3	149117.4	54656.3	158187.3	38630.1	27858.2	47140.5	54890.8	70351.0	130408.4	104751.1	32113.9	51009.7	5133606.8	6559797.3

Imported Intermediate Use Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Subtotal
1	21259.7	54276.9	57.2	10.7	8.3	72.9	134623.7	5732.5	33.2	342.6	665.6	24.4	14.5	21.1	122.6	9.9	25.3	9104.5	226405.5
2	45.1	3.4	133.2	20.0	13.4	95.4	80.0	116.5	38.1	47.3	109.4	46.6	25.3	36.3	26.8	12.0	21.3	2663.1	3533.2
3	0.0	0.0	2688.8	26.2	0.5	31.3	5.8	60.7	2.1	0.6	0.0	0.0	0.0	0.0	0.0	0.8	11.5	4289.8	7118.1
4	2.5	2.2	14.8	3405.5	8.9	1039.2	2.7	6.5	121.6	5.5	2.2	14.2	27.7	7.7	1233.9	73.1	484.5	4873.1	11325.6
5	16.9	87.6	125.2	50.7	4574.9	735.8	14.8	71.6	40.8	78.6	104.5	67.7	117.1	70.7	177.3	69.4	2010.6	15606.7	24020.9
6	34.5	23.7	2206.0	79.6	52.0	8893.7	93.7	742.9	430.8	205.5	65.4	166.9	191.2	507.8	174.8	26.5	535.2	10434.3	24864.7
7	2365.3	1282.2	407.2	49.4	105.5	815.9	8331.9	4715.9	262.4	129.9	872.9	260.6	240.8	103.7	162.5	170.2	85.7	46199.8	66561.8
8	1473.0	77.5	1471.2	3549.7	360.0	3764.8	1750.6	35354.7	13844.8	745.9	674.4	1190.6	918.2	2034.8	1706.2	727.2	1757.3	33888.7	105289.5
9	173.6	81.7	1992.8	79.5	81.8	632.9	72.4	1419.5	1463.5	114.1	60.8	177.9	851.1	692.8	1727.8	338.4	1138.0	12056.2	23154.7
10	255.5	150.0	553.5	26.8	121.9	35.4	208.5	215.6	157.0	1779.7	641.0	141.8	210.3	180.5	587.6	104.2	141.2	12859.9	18370.3
11	1243.3	169.1	7.9	1.4	6.3	180.7	12.4	103.9	316.4	255.6	26622.6	14788.9	8824.2	4093.6	9955.8	2256.3	2278.1	5123.8	76240.3
12	532.4	164.7	1351.7	64.5	227.9	533.7	220.3	672.3	282.0	158.8	702.3	3196.2	3003.4	1576.7	2925.5	1701.4	863.6	13436.6	31614.3
13	2530.1	90.1	400.4	104.6	368.9	740.4	33.8	799.4	629.0	56.8	1133.6	1076.9	8646.0	1326.7	7573.0	1912.6	503.2	25003.1	52928.7
14	242.3	681.5	799.2	417.4	460.5	4148.5	412.7	1705.9	1197.0	437.2	2134.1	1395.9	6508.9	43701.7	8013.7	6150.7	1673.3	67425.1	147505.4
15	280.0	24.6	73.5	4.4	50.9	49.9	34.1	38.6	4.6	29.3	14.6	64.4	1079.2	97.9	41234.3	372.6	19.1	20140.2	63612.2
16	3.4	0.8	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	1.0	14.2	0.0	29.7	4939.1	0.0	11177.8	16166.1
17	42.5	15.2	83.0	95.8	736.7	55.3	6.3	264.9	86.5	38.6	58.9	88.4	260.4	360.5	205.5	113.5	3383.3	23323.8	29219.0
18	250.9	165.3	7546.5	229.1	3003.8	2236.6	303.8	818.0	495.2	195.9	523.4	288.0	358.1	709.5	711.6	245.7	300.0	48508.6	66890.0

Value Added and Tax (Subsidy)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Subtotal
19	154961.9	142115.8	56317.2	11539.5	13090.6	98212.1	54900.3	113036.6	24902.5	23719.6	22722.6	40079.1	36524.1	56251.9	19706.3	22081.8	35940.6	3631697.8	4557800.4
20	49425.0	55701.0	81578.3	27705.0	24759.0	139654.3	14018.0	82832.0	40303.0	28100.0	31520.0	81552.0	81856.4	110812.4	75970.0	57381.0	65873.0	5949695.3	6998735.7
21	19427.8	41636.8	21310.6	1056.0	587.0	4760.7	1985.0	5628.0	1854.0	1198.0	2108.0	2101.0	2002.9	1444.8	2549.0	1110.0	1264.0	753325.7	865349.3

Table B.3: Final Demand of Domestic/Imported Goods and Trade

	Final consumption of domestic goods						Final consumption of imported goods						Trade			
	19	20	21	22	subtotal		19	20	21	22	subtotal		23	24	25	26
1	8845.8	706.5	77620.7	8653.7	95826.6		0.0	0.0	0.0	0.0	0.0		10431.2	930.3	228824.100	-3348.9
2	186687.3	2.5	14745.4	-11221.9	190213.4		0.0	0.0	0.0	0.0	0.0		1246.0	0.0	2479.500	1053.7
3	382355.9	3016.0	1000.8	5144.3	391517.1		53829.0	0.0	0.0	0.0	53829.0		32737.9	3095.1	51922.100	5929.8
4	29570.8	-41.4	4286.7	3218.8	37034.9		147997.4	0.0	0.0	0.0	147997.4		15682.4	46225.8	81039.000	32058.3
5	486.2	-52.0	6912.1	1846.9	9193.1		1929.3	0.0	0.0	0.0	1929.3		4038.2	3070.4	22924.000	-44.2
6	84277.1	-154.9	79443.2	1933.5	165498.8		9284.4	0.0	860.6	335.0	10480.0		31280.9	3193.6	25427.200	6723.9
7	172617.9	-0.2	755.1	2664.3	176037.1		0.0	0.0	0.0	0.0	0.0		24470.3	669.9	72384.700	-6492.8
8	165649.6	-3.9	3901.7	5438.8	174986.2		50495.1	0.0	0.0	0.0	50495.1		93681.7	6212.2	125266.300	24306.1
9	15601.5	-49.8	1469.9	2162.3	19183.9		10042.6	0.0	0.0	0.0	10042.6		16787.4	9277.6	27417.900	-3498.2
10	3571.0	-3.3	204.9	1142.3	4914.9		3356.8	0.0	0.0	0.0	3356.8		5912.6	4474.1	16263.000	990.0
11	1376.8	-401.1	772.0	4804.5	6552.2		0.0	0.0	0.0	0.0	0.0		20115.3	3618.5	62267.500	10354.3
12	7261.9	-430.8	12462.6	4313.7	23607.4		6680.8	0.0	2608.9	0.0	9289.7		21776.6	10033.0	24797.200	6073.9
13	21870.0	-415.4	117360.6	3292.0	142107.2		12119.4	0.0	40449.0	0.0	52568.4		86631.4	17929.3	103024.000	-15456.2
14	49291.0	-10.0	103322.5	9697.1	162300.6		27976.6	0.0	79069.7	0.0	107046.3		130102.4	100934.7	252394.500	-98777.5
15	153153.2	-271.6	99843.1	-1033.8	251690.9		73651.9	0.0	62560.6	0.0	136212.6		73988.1	3223.6	205059.500	-8458.3
16	14453.9	-6.0	55102.6	4002.3	73552.7		6950.3	0.0	7606.66	0.0	14557.0		67262.5	1961.7	33851.100	-5089.8
17	61871.6	-14.9	64073.0	2934.1	128863.8		72144.7	0.0	7999.1	0.0	80143.8		28005.5	41206.2	51918.500	16238.2
18	6809664.3	1955603.8	1594484.5	-8014.7	10351737.9		49049.4	0.0	1645.8	2020.7	52715.9		347663.7	3773.4	85231.600	30600.9
subtotal	8168605.8	1957473.5	2237761.3	40978.1	12404818.7		525507.8	0.0	202800.4	2355.7	730663.8		1011813.9	259829.4	1472491.7	-6836.8

Table B.4: Imported Intermediate Use

Imported Intermediate Use from China

	Energy		Manufacturing														Others	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Subtotal
1	86.1	219.8	0.2	0	0	0.3	545.1	23.2	0.1	1.4	2.7	0.1	0.1	0.1	0.5	0	0.1	36.9	916.7
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	205.9	2	0	2.4	0.4	4.6	0.2	0	0	0	0	0	0	0.1	0.9	328.6	545.1
4	0.4	0.3	2.4	541	1.4	165.1	0.4	1	19.3	0.9	0.3	2.3	4.4	1.2	196	11.6	77	774.2	1799.2
5	1.3	6.8	9.7	3.9	354.2	57	1.1	5.5	3.2	6.1	8.1	5.2	9.1	5.5	13.7	5.4	155.7	1208.5	1860
6	2.7	1.9	173.6	6.3	4.1	699.9	7.4	58.5	33.9	16.2	5.1	13.1	15	40	13.8	2.1	42.1	821.2	1956.9
7	21.7	11.8	3.7	0.5	1	7.5	76.4	43.2	2.4	1.2	8	2.4	2.2	1	1.5	1.6	0.8	423.7	610.6
8	74.8	3.9	74.7	180.3	18.3	191.3	88.9	1796	703.3	37.9	34.3	60.5	46.6	103.4	86.7	36.9	89.3	1721.5	5348.6
9	29.4	13.8	337	13.4	13.8	107	12.2	240.1	247.5	19.3	10.3	30.1	143.9	117.2	292.2	57.2	192.5	2039	3915.9
10	43	25.3	93.2	4.5	20.5	6	35.1	36.3	26.4	299.6	107.9	23.9	35.4	30.4	98.9	17.5	23.8	2165.1	3092.8
11	68.3	9.3	0.4	0.1	0.3	9.9	0.7	5.7	17.4	14	1462.1	812.2	484.6	224.8	546.8	123.9	125.1	281.4	4187
12	121.4	37.5	308.1	14.7	52	121.7	50.2	153.3	64.3	36.2	160.1	728.6	684.7	359.4	666.9	387.9	196.9	3063	7206.9
13	171	6.1	27.1	7.1	24.9	50	2.3	54	42.5	3.8	76.6	72.8	584.2	89.6	511.7	129.2	34	1689.5	3576.4
14	30.2	85	99.6	52	57.4	517.2	51.5	212.7	149.2	54.5	266.1	174	811.5	5448.6	999.1	766.8	208.6	8406.3	18390.3
15	11	1	2.9	0.2	2	2	1.3	1.5	0.2	1.1	0.6	2.5	42.2	3.8	1614.2	14.6	0.7	788.4	2490.2
16	0.1	0	0	0	0	0	0	0	0	0	0	0	0.3	0	0.7	109.5	0	247.9	358.5
17	5.1	1.8	10	11.5	88.5	6.6	0.8	31.8	10.4	4.6	7.1	10.6	31.3	43.3	24.7	13.6	406.3	2800.9	3508.9
18	1.8	1.2	54.4	1.7	21.6	16.1	2.2	5.9	3.6	1.4	3.8	2.1	2.6	5.1	5.1	1.8	2.2	349.5	482.1

Imported Intermediate Use from the rest of world

	Energy		Manufacturing														Others	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Subtotal
1	21173.6	54057.1	57	10.7	8.3	72.6	134078.6	5709.3	33.1	341.2	662.9	24.3	14.4	21	122.1	9.9	25.2	9067.6	225488.9
2	45.1	3.4	133.2	20	13.4	95.4	80	116.5	38.1	47.3	109.4	46.6	25.3	36.3	26.8	12	21.3	2663.1	3533.2
3	0	0	2482.9	24.2	0.5	28.9	5.4	56.1	1.9	0.6	0	0	0	0	0	0.7	10.6	3961.2	6573
4	2.1	1.9	12.4	2864.4	7.5	874.1	2.3	5.5	102.3	4.6	1.9	11.9	23.3	6.5	1037.8	61.5	407.5	4098.8	9526.3
5	15.6	80.8	115.5	46.8	4220.7	678.8	13.7	66.1	37.6	72.5	96.4	62.5	108	65.2	163.6	64	1854.9	14398.2	22160.9
6	31.8	21.8	2032.4	73.3	47.9	8193.9	86.3	684.4	396.9	189.3	60.3	153.8	176.2	467.8	161	24.4	493.1	9613.2	22907.8
7	2343.6	1270.4	403.5	48.9	104.5	808.4	8255.5	4672.7	260	128.7	864.9	258.2	238.6	102.7	161	168.6	84.9	45776.1	65951.2
8	1398.2	73.6	1396.5	3369.4	341.7	3573.5	1661.7	33558.6	13141.5	708	640.1	1130.1	871.6	1931.4	1619.5	690.3	1668	32167.1	99940.8
9	144.2	67.9	1655.8	66.1	68	525.9	60.2	1179.4	1216	94.8	50.5	147.8	707.2	575.6	1435.6	281.2	945.5	10017.1	19238.8
10	212.5	124.7	460.3	22.3	101.4	29.4	173.4	179.3	130.6	1480.1	533.1	117.9	174.9	150.1	488.7	86.7	117.4	10694.8	15277.6
11	1175	159.8	7.5	1.3	6	170.8	11.7	98.2	299	241.6	25160.5	13976.7	8339.6	3868.8	9409	2132.4	2153	4842.4	72053.3
12	411	127.2	1043.6	49.8	175.9	412	170.1	519	217.7	122.6	542.2	2467.6	2318.8	1217.3	2258.6	1313.6	666.7	10373.6	24407.3
13	2359.1	84	373.3	97.5	344	690.4	31.5	745.4	586.5	53	1057	1004.1	8061.8	1237.1	7061.3	1783.4	469.2	23313.7	49352.3
14	212.1	596.5	699.6	365.4	403.1	3631.3	361.2	1493.2	1047.8	382.7	1868	1221.9	5697.4	38253.1	7014.6	5383.8	1464.7	59018.7	129115.1
15	269	23.6	70.6	4.2	48.9	47.9	32.8	37.1	4.4	28.2	14	61.9	1037	94.1	39620.1	358	18.4	19351.7	61121.9
16	3.3	0.8	0	0	0.1	0	0	0	0	0	0	1	13.9	0	29	4829.6	0	10929.9	15807.6
17	37.4	13.4	73	84.3	648.2	48.7	5.5	233.1	76.1	34	51.8	77.8	229.1	317.2	180.8	99.9	2977	20522.9	25710.2
18	249.1	164.1	7492.1	227.4	2982.2	2220.5	301.6	812.1	491.6	194.5	519.6	285.9	355.5	704.4	706.5	243.9	297.8	48159.1	66407.9

APPENDIX C

Empirical Results of All Specifications

Table C.1: Pooled OLS Estimation on the Quantity of Energy

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
lgpenCHN	0.00955	0.00676	0.00705	0.0234	-0.188***	-0.194***	-0.808***	-1.029***	-0.799***	-0.764***
	(0.00962)	(0.00923)	(0.00918)	(0.0155)	(0.0512)	(0.0583)	(0.210)	(0.235)	(0.207)	(0.208)
lgLK	0.0657	0.0826	-0.213	-0.107	-0.309	0.115	-0.405*	-0.0110	-0.299	-0.227
	(0.0849)	(0.0763)	(0.251)	(0.251)	(0.257)	(0.348)	(0.241)	(0.323)	(0.276)	(0.280)
lgvship	0.520***	1.355***	1.525***	1.456***	1.492***	1.286***	2.261***	2.316***	2.147***	1.932***
	(0.0565)	(0.227)	(0.260)	(0.285)	(0.275)	(0.285)	(0.313)	(0.348)	(0.291)	(0.292)
sqlgvship		-0.0508***	-0.0580***	-0.0551***	-0.0495***	-0.0393**	-0.0968***	-0.103***	-0.0922***	-0.0820***
		(0.0131)	(0.0144)	(0.0157)	(0.0154)	(0.0162)	(0.0176)	(0.0209)	(0.0164)	(0.0161)
LKvship			0.0355	0.0312	0.0512*	-0.00807	0.0623**	0.00660	0.0497	0.0448
			(0.0303)	(0.0300)	(0.0309)	(0.0435)	(0.0286)	(0.0401)	(0.0347)	(0.0344)
penCHNLK				0.0125	0.00333	-0.0360**	0.000784	-0.0401**	-0.00242	0.00671
				(0.00795)	(0.00790)	(0.0155)	(0.00787)	(0.0156)	(0.0169)	(0.0154)
penCHNvship					0.0238***	0.0215***	0.173***	0.222***	0.172***	0.167***
					(0.00591)	(0.00691)	(0.0475)	(0.0539)	(0.0472)	(0.0473)
penCHNsqLK						-0.00924*		-0.00953*	-0.00163	0.000120
						(0.00526)		(0.00525)	(0.00553)	(0.00500)
penCHNsqvship							-0.00885***	-0.0119***	-0.00891***	-0.00873***
							(0.00264)	(0.00307)	(0.00264)	(0.00264)
lgNfirm									0.0861	0.0774
									(0.0554)	(0.0550)
lgtfp										0.246***
										(0.0799)
Constant	11.62***	8.254***	7.353***	7.809***	7.082***	7.555***	4.008***	3.447**	4.149***	5.306***
	(0.522)	(1.050)	(1.219)	(1.356)	(1.305)	(1.346)	(1.445)	(1.514)	(1.360)	(1.392)
Observations	3,313	3,313	3,313	3,313	3,313	3,296	3,313	3,296	3,313	3,313
R-squared	0.380	0.401	0.402	0.405	0.416	0.439	0.425	0.451	0.428	0.435
Number of NAICS	380	380	380	380	380	380	380	380	380	380

Table C.2: IV Estimation on the Quantity of Energy

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
lgpenCHN	0.113***	0.0959***	0.0973***	0.108***	-0.00247	0.0517	-0.136	-0.103	-0.0807	-0.0334
	(0.0196)	(0.0194)	(0.0193)	(0.0209)	(0.0739)	(0.0780)	(0.233)	(0.238)	(0.238)	(0.234)
lgLK	0.0684	0.0866**	-0.318**	-0.200	-0.296*	0.0339	-0.317*	0.00334	0.0157	0.146
	(0.0461)	(0.0422)	(0.152)	(0.161)	(0.168)	(0.198)	(0.167)	(0.200)	(0.199)	(0.196)
lgvship	0.542***	1.308***	1.542***	1.469***	1.484***	1.159***	1.635***	1.339***	1.298***	1.080***
	(0.0322)	(0.122)	(0.146)	(0.158)	(0.158)	(0.171)	(0.255)	(0.284)	(0.284)	(0.278)
sqlgvship		-0.0469***	-0.0568***	-0.0538***	-0.0511***	-0.0354***	-0.0602***	-0.0461***	-0.0445***	-0.0353**
		(0.00718)	(0.00814)	(0.00859)	(0.00857)	(0.00906)	(0.0147)	(0.0160)	(0.0160)	(0.0155)
LKvship			0.0488***	0.0427**	0.0522***	0.0145	0.0547***	0.0182	0.0158	0.00689
			(0.0182)	(0.0180)	(0.0189)	(0.0232)	(0.0191)	(0.0238)	(0.0237)	(0.0229)
penCHNLK				0.0125	0.00801	-0.0189	0.00760	-0.0188	-0.0179	-0.00252
				(0.00856)	(0.00851)	(0.0121)	(0.00834)	(0.0121)	(0.0120)	(0.0120)
penCHNvship					0.0117	0.00503	0.0424	0.0405	0.0353	0.0305
					(0.00720)	(0.00773)	(0.0496)	(0.0499)	(0.0499)	(0.0487)
penCHNsqLK						-0.0113***		-0.0110***	-0.0104***	-0.00821**
						(0.00365)		(0.00368)	(0.00368)	(0.00343)
penCHNsqvship							-0.00177	-0.00204	-0.00177	-0.00170
							(0.00274)	(0.00272)	(0.00271)	(0.00262)
lgNfirm									0.0558*	0.0497*
									(0.0292)	(0.0290)
lgtfp										0.233***
										(0.0543)
Observations	3,204	3,204	3,204	3,204	3,204	3,204	3,204	3,204	3,204	3,204
R-squared	0.301	0.343	0.344	0.353	0.371	0.362	0.377	0.369	0.372	0.380
Number of NAICS	363	363	363	363	363	363	363	363	363	363

Table C.3: Pooled OLS Estimation on the Quantity of Fuel

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
lgpenCHN	0.0116	0.00838	0.00838	0.00302	-0.226***	-0.194***	-1.054***	-1.029***	-1.024***	-1.002***
	(0.00975)	(0.00945)	(0.00947)	(0.0162)	(0.0553)	(0.0583)	(0.227)	(0.235)	(0.228)	(0.230)
lgLK	0.0796	0.0996	0.0983	0.0636	-0.160	0.115	-0.292	-0.0110	0.0556	0.102
	(0.0965)	(0.0878)	(0.318)	(0.318)	(0.326)	(0.348)	(0.298)	(0.323)	(0.316)	(0.320)
lgvship	0.545***	1.503***	1.503***	1.526***	1.566***	1.286***	2.594***	2.316***	2.229***	2.086***
	(0.0728)	(0.257)	(0.285)	(0.294)	(0.289)	(0.285)	(0.356)	(0.348)	(0.342)	(0.345)
sqlgvship		-0.0583***	-0.0583***	-0.0593***	-0.0532***	-0.0393**	-0.116***	-0.103***	-0.100***	-0.0934***
		(0.0150)	(0.0159)	(0.0163)	(0.0163)	(0.0162)	(0.0213)	(0.0209)	(0.0205)	(0.0204)
LKvship			0.000163	0.00158	0.0237	-0.00807	0.0392	0.00660	-0.00193	-0.00497
			(0.0389)	(0.0387)	(0.0398)	(0.0435)	(0.0362)	(0.0401)	(0.0394)	(0.0395)
penCHNLK				-0.00408	-0.0140*	-0.0360**	-0.0174**	-0.0401**	-0.0356**	-0.0296*
				(0.00846)	(0.00820)	(0.0155)	(0.00833)	(0.0156)	(0.0157)	(0.0156)
penCHNvship					0.0258***	0.0215***	0.225***	0.222***	0.222***	0.219***
					(0.00638)	(0.00691)	(0.0522)	(0.0539)	(0.0522)	(0.0526)
penCHNsqLK						-0.00924*		-0.00953*	-0.00817	-0.00700
						(0.00526)		(0.00525)	(0.00522)	(0.00507)
penCHNsqvship							-0.0118***	-0.0119***	-0.0120***	-0.0119***
							(0.00298)	(0.00307)	(0.00298)	(0.00300)
lgNfirm									0.165***	0.159**
									(0.0624)	(0.0625)
lgtfp										0.165*
										(0.0949)
Constant	10.99***	7.126***	7.122***	6.973***	6.185***	7.555***	2.073	3.447**	3.060**	3.831**
	(0.668)	(1.192)	(1.349)	(1.410)	(1.387)	(1.346)	(1.570)	(1.514)	(1.522)	(1.574)
Observations	3,296	3,296	3,296	3,296	3,296	3,296	3,296	3,296	3,296	3,296
R-squared	0.403	0.424	0.424	0.425	0.435	0.439	0.447	0.451	0.459	0.462
Number of NAICS	380	380	380	380	380	380	380	380	380	380

Table C.4: IV Estimation on the Quantity of Fuel

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
lgpenCHN	0.0907***	0.0705***	0.0707***	0.0571***	-0.0879	0.00726	-0.478**	-0.419*	-0.366	-0.346
	(0.0203)	(0.0202)	(0.0202)	(0.0212)	(0.0754)	(0.0812)	(0.235)	(0.241)	(0.240)	(0.238)
lgLK	0.0829	0.106**	0.0273	-0.118	-0.245	0.334	-0.308	0.247	0.276	0.336
	(0.0525)	(0.0486)	(0.174)	(0.192)	(0.201)	(0.227)	(0.199)	(0.226)	(0.226)	(0.223)
lgvship	0.561***	1.485***	1.530***	1.620***	1.640***	1.069***	2.081***	1.566***	1.465***	1.363***
	(0.0396)	(0.141)	(0.165)	(0.174)	(0.176)	(0.191)	(0.283)	(0.310)	(0.309)	(0.304)
sqlgvship		-0.0566***	-0.0585***	-0.0621***	-0.0585***	-0.0309***	-0.0850***	-0.0605***	-0.0565***	-0.0523***
		(0.00839)	(0.00920)	(0.00948)	(0.00954)	(0.0100)	(0.0162)	(0.0175)	(0.0173)	(0.0170)
LKvship			0.00943	0.0169	0.0296	-0.0364	0.0372*	-0.0260	-0.0318	-0.0359
			(0.0207)	(0.0211)	(0.0220)	(0.0255)	(0.0218)	(0.0254)	(0.0254)	(0.0250)
penCHNLK				-0.0154	-0.0211**	-0.0684***	-0.0222**	-0.0682***	-0.0659***	-0.0586***
				(0.00959)	(0.00963)	(0.0117)	(0.00957)	(0.0117)	(0.0115)	(0.0120)
penCHNvship					0.0153**	0.00358	0.105**	0.102**	0.0891*	0.0872*
					(0.00735)	(0.00804)	(0.0498)	(0.0502)	(0.0498)	(0.0494)
penCHNsqLK						-0.0198***		-0.0192***	-0.0176***	-0.0165***
						(0.00346)		(0.00350)	(0.00346)	(0.00347)
penCHNsqvship							-0.00517*	-0.00562**	-0.00498*	-0.00497*
							(0.00272)	(0.00270)	(0.00267)	(0.00265)
lgNfirm									0.140***	0.137***
									(0.0336)	(0.0338)
lgtfp										0.111*
										(0.0626)
Observations	3,187	3,187	3,187	3,187	3,187	3,187	3,187	3,187	3,187	3,187
R-squared	0.367	0.402	0.402	0.396	0.412	0.407	0.425	0.422	0.430	0.432
Number of NAICS	363	363	363	363	363	363	363	363	363	363

Table C.5: Pooled OLS Estimation on the Quantity of Electricity

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
lgpenCHN	0.00387	0.00120	0.00187	0.0360**	-0.0866	-0.113*	-0.296	-0.316	-0.316	-0.272
	(0.0106)	(0.0105)	(0.0104)	(0.0167)	(0.0614)	(0.0592)	(0.266)	(0.255)	(0.255)	(0.252)
lgLK	0.0840	0.101	-0.568**	-0.348	-0.467*	-0.694**	-0.501*	-0.724**	-0.717**	-0.623**
	(0.0866)	(0.0798)	(0.242)	(0.248)	(0.256)	(0.306)	(0.265)	(0.310)	(0.309)	(0.303)
lgvship	0.472***	1.272***	1.656***	1.512***	1.533***	1.764***	1.793***	2.014***	2.004***	1.718***
	(0.0601)	(0.223)	(0.259)	(0.290)	(0.283)	(0.290)	(0.375)	(0.360)	(0.359)	(0.348)
sqlgvship		-0.0487***	-0.0650***	-0.0590***	-0.0557***	-0.0671***	-0.0717***	-0.0826***	-0.0823***	-0.0688***
		(0.0126)	(0.0139)	(0.0154)	(0.0153)	(0.0157)	(0.0204)	(0.0197)	(0.0197)	(0.0187)
LKvship			0.0804***	0.0714***	0.0832***	0.109***	0.0871***	0.113***	0.112***	0.106***
			(0.0278)	(0.0269)	(0.0276)	(0.0377)	(0.0286)	(0.0379)	(0.0377)	(0.0361)
penCHNLK				0.0260***	0.0207**	0.0389*	0.0198**	0.0379*	0.0384*	0.0506***
				(0.00920)	(0.00952)	(0.0204)	(0.00948)	(0.0205)	(0.0206)	(0.0180)
penCHNvship					0.0138**	0.0173**	0.0642	0.0662	0.0662	0.0604
					(0.00696)	(0.00699)	(0.0600)	(0.0583)	(0.0582)	(0.0576)
penCHNsqLK						0.00764		0.00757	0.00773	0.0101*
						(0.00646)		(0.00648)	(0.00651)	(0.00567)
penCHNsqvship							-0.00299	-0.00290	-0.00291	-0.00270
							(0.00331)	(0.00327)	(0.00327)	(0.00323)
lgNfirm									0.0192	0.00770
									(0.0664)	(0.0653)
lgtfp										0.330***
										(0.0908)
Constant	10.77***	7.545***	5.514***	6.464***	6.041***	4.909***	5.001***	3.910**	3.865**	5.406***
	(0.555)	(1.058)	(1.265)	(1.445)	(1.410)	(1.407)	(1.768)	(1.674)	(1.696)	(1.671)
Observations	3,296	3,296	3,296	3,296	3,296	3,296	3,296	3,296	3,296	3,296
R-squared	0.304	0.323	0.329	0.339	0.342	0.346	0.343	0.347	0.347	0.359
Number of NAICS	380	380	380	380	380	380	380	380	380	380

Table C.6: IV Estimation on the Quantity of Electricity

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
lgpenCHN	0.0928***	0.0769***	0.0793***	0.109***	0.121	0.109	0.488*	0.481*	0.479*	0.545*
	(0.0230)	(0.0230)	(0.0229)	(0.0243)	(0.0882)	(0.0897)	(0.285)	(0.288)	(0.288)	(0.282)
lgLK	0.0878*	0.106**	-0.685***	-0.371**	-0.360*	-0.437*	-0.301	-0.361	-0.362	-0.165
	(0.0474)	(0.0443)	(0.171)	(0.182)	(0.198)	(0.228)	(0.208)	(0.244)	(0.245)	(0.236)
lgvship	0.494***	1.222***	1.677***	1.482***	1.480***	1.556***	1.066***	1.121***	1.126***	0.795**
	(0.0342)	(0.128)	(0.147)	(0.160)	(0.162)	(0.186)	(0.326)	(0.359)	(0.361)	(0.348)
sqlgvship		-0.0446***	-0.0638***	-0.0560***	-0.0563***	-0.0599***	-0.0314*	-0.0340*	-0.0342*	-0.0203
		(0.00743)	(0.00803)	(0.00844)	(0.00818)	(0.00924)	(0.0185)	(0.0200)	(0.0201)	(0.0191)
LKvship			0.0953***	0.0791***	0.0781***	0.0868***	0.0709***	0.0777***	0.0779***	0.0647**
			(0.0200)	(0.0196)	(0.0212)	(0.0258)	(0.0226)	(0.0281)	(0.0281)	(0.0267)
penCHNLK				0.0331***	0.0336***	0.0398***	0.0347***	0.0396***	0.0395***	0.0632***
				(0.00971)	(0.0101)	(0.0148)	(0.0103)	(0.0150)	(0.0151)	(0.0140)
penCHNvship					-0.00131	0.000230	-0.0857	-0.0854	-0.0847	-0.0910
					(0.00818)	(0.00849)	(0.0599)	(0.0600)	(0.0602)	(0.0581)
penCHNsqLK						0.00261		0.00206	0.00198	0.00533
						(0.00442)		(0.00449)	(0.00451)	(0.00399)
penCHNsqvship							0.00486	0.00491	0.00488	0.00492
							(0.00330)	(0.00328)	(0.00329)	(0.00314)
lgNfirm									-0.00689	-0.0162
									(0.0340)	(0.0337)
lgtfp										0.359***
										(0.0604)
Observations	3,187	3,187	3,187	3,187	3,187	3,187	3,187	3,187	3,187	3,187
R-squared	0.252	0.286	0.292	0.316	0.314	0.317	0.303	0.305	0.305	0.316
Number of naics	363	363	363	363	363	363	363	363	363	363