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Energy and Carbon Embodied in the Exports of Taiwan: An Input-Output Structural Decomposition Analysis

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This paper computes the energy and carbon intensities of the Taiwanese economy in 1996, 2001 and 2006 to figure out the changes in energy and carbon embodied in products and exports and the contributing factors. We use structural decomposition analysis to find the relative contribution of five factors causing the changes in the energy and carbon embodied in exports. From 1996 to 2001, the changes in the direct energy efficiency, the structure of intermediate inputs and the structure of exports were the most important factors contributing to the changes of energy and carbon embodied in Taiwan's exports. Between 2001 and 2006, the structure of exports has been the most important factor causing the changes. This paper also explores whether energy policy could have effectively reduced the energy and carbon embodied in Taiwan's exports. Our results show imposing a carbon tax on using fossil fuels would have decreased the carbon embodied in exports only moderately from 1996 to 2001. However, the carbon embodied in exports would have decreased significantly from 2001 to 2006 after taxation, implying that a carbon tax would have been a more effective policy in the latter period.

Keywords: embodied carbon, input-output, structural decomposition analysis, carbon tax
JEL classification: F18, Q48, Q56

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1 Introduction

There is an increasing concern about climate change around the world. CO_2 is one of the major greenhouse gases (GHG) causing global warming. According to the 4^{th} assessment report of the International Panel on Climate Change (IPCC), CO_2 is 76% of the global GHG emissions in 2004 (Lin and Li, 2011). The Taiwan Environmental Protection Administration (EPA) also indicates that the country's per capita CO_2 emissions are three times higher than that of the global average. Of the world's total CO_2 emissions, Taiwan is currently ranked 21st in the world (IEA, 2016). Therefore, efforts to reduce CO_2 emissions have become imperative and are gaining momentum all around the world. Nations are becoming more conscious of their carbon footprints.[1] They now compute the CO_2 emissions in the production process of a product.

Due to Taiwan's geographical position and lack of natural resources, the country has been focusing on international trade as a source of income. According to the Directorate General of Budget, Accounting and Statistics (DGBAS), the country's export earnings in proportion to its GDP has been increasing from 1981 to 2011. This shows that international trade is becoming a major economic activity in Taiwan.

A majority of Taiwan's industries rely on fossil fuels which have led to increasing CO_2 emissions. IPCC reveals that fossil fuel consumption contributes 56.6% of the CO_2 emissions in Global anthropogenic greenhouse gas emissions in 2004 (4^{th} Assessment Report of the IPCC; IPCC (2007)). Hence, the environmental impact of fuel combustion has become the main focus in studies concerning CO_2 emissions.

Due to increasing concerns over CO_2 emissions, many countries have entered into agreements to reduce their CO_2 emissions. Consequently, if a country is not a signatory of such an agreement, the member countries can impose a carbon tariff on goods exported by them. Embodied carbon in commodities may become one of the competitive factors that importing countries will consider in the future. Looking at the case of Korea, they are the world's 10^{th} largest emitter of energy-related CO_2 as of 2005 (IEA, 2007). Because of this, they are focusing their efforts on carbon mitigation initiatives. Such initiatives include putting product labels that indicate how

[1] Carbon footprint can be defined as the total direct and indirect CO_2 emissions resulting from an activity, organization, person, or product.

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much carbon was emitted in the manufacturing process, and giving "green cards[2]" to consumers in order to encourage the purchase of green products (Low Carbon Green Growth Roadmap for Asia and the Pacific; United Nations (2012)).

Given the factors mentioned above, the purpose of this paper is to estimate the energy and carbon embodied in exports of Taiwan and to determine what factors cause the fluctuation of energy and carbon embodied in exports. Furthermore, this paper aims to simulate the imposition of a carbon tax on commodities of industries as part of the government's energy policy, and test whether it lowers carbon embodied in exports. Previous literatures dealing with the above-mentioned issues have mostly applied the index decomposition analysis (IDA) or structural decomposition analysis (SDA). IDA has been applied mainly to aggregate analysis. For example, Greening, Davis, and Schipper (1998) applied the Adaptive Weighted Divisia rolling base year index to figure out the major factors attributing to the changes of total carbon emissions of the manufacturing sector of 10 OECD countries for the period 1971–1991. Greening, Ting, and Krackler (2001) further applied the same approach to examine the most important factors which have caused carbon emissions from the residential sector of 10 OECD countries to change over the 1970–1993 periods. IDA can also be formulated under the input-output framework. For instance, Chung (1998) and Chung and Rhee (2001) developed methods to decompose sources of carbon dioxide emissions using a combined index and input–output approach. The method used by Chung and Rhee (2001) used 'mean rate-of-change index' for weights of the decomposed terms. They claimed that it is particularly useful for decomposing sources of changes in emissions using the input–output framework, which often involves data set with negative values (i.e. inventory). However, the major shortcoming of this method is that subjective judgement has inevitably involved in the specification of the weights of the index.

SDA has mostly been specified under the input-output framework to take into account the direct and indirect industrial linkages among industries of the economy. Different from the IDA approach, SDA usually does not

[2]The Korean Ministry of Environment introduced a green credit card in 2011 to encourage consumers to adopt a more sustainable lifestyle by providing economic incentives. Points are accumulated as rewards for saving on utility use (tap water, electricity and gas heating), using public transport, or purchasing eco-friendly products.

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involve a subjective specification of weights for decomposed terms. Over the past decades, SDA has been widely applied in energy analysis (Chen and Rose, 1990; Rose and Chen, 1991), and many studies have even extended it to study the driving forces of carbon dioxide and other emissions within economies (Casler and Rose, 1998; Chang and Lin, 1998; Liu and Ang, 2007; Wood and Lenzen, 2009; Liu et al., 2010; Chang, 2013). In this paper, we follow this trend by using SDA together with input-output models to conduct our analysis.

The remainder of this paper is organized as follows: Section 2 describes the background of the energy and carbon embodied in international trade. Section 3 explains the possible effect of a carbon tax on CO_2 emissions. Section 4 shows some methods adopted to calculate the energy and carbon embodied event. Finally, Section 5 and 6 discusses the empirical results and conclusions, respectively.

2 Energy and Carbon Embodied in Trade

There has been long-lasting argument regarding the relationship between trade and the environment over the last several decades. Some analysts argue that trade is inherently good for the environment. The core of this thought revolves around the law of comparative advantage (Buterbaugh, 2008). Every region or country is endowed with different mixes of resources, capital and labor. Then, these different mixes make each region or country better at producing some specific things than others. However, some analysts advocate trade is bad for the environment. Buterbaugh (2008) listed several reasons for this inherent conflict. First of all, trade leads to economic growth and which causes a greater demand for resources, thus harming the environment. Then, free-trade goods are always shipped over long distances. It is also regarded as damaging the environment. Moreover, many developing countries do not have the governmental capacity to manage the actions of their citizens or domestic and foreign firms appropriately. Then, free trade may also be seen as one of the reason for the despoliation of vast area of the developing world. Finally, free trade may arouse the conflict over resources. Many countries have competed fiercely with each other for controlling different various resources. All of the reasons above are seen as responsible for harming the environment.

According to the World Trade Organization (WTO), international trade might accelerate the depletion of natural resources and the degradation of

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the environment (Nordströmm and Vaughan, 1999). All goods and services in an economy are directly and/or indirectly associated with energy use and pollution (Lenzen, 1998; Machado, Schaeffer, and Worrell, 2001; Peters and Hertwich, 2006). Some studies also identified three kinds of impacts on the environment and on natural resource related to international trade.[3] These are: scale, composition and technical effects. The energy and pollutant flows towards and from a country are affected by the mix of exported and imported products, and the technical efficiency in processing the products and their inputs (Machado, Schaeffer, and Worrell, 2001). Furthermore, a country's fast-growing economy and increased international trade might cause the over exploitation of resources (Liu et al., 2010). Therefore, a more complete and balanced information on energy use associated with international trade is needed for all countries across the globe (Mäenpää and Siikavirta, 2007).

Input-output analysis which has been widely used in analyzing the energy embodied in goods and services is first designed by Wassily Leontief (1936). Each industry's production can be represented by a transaction matrix of intermediate input and final demand through this model. Then, the application of input-output techniques allows one to trace the direct and indirect energy/environmental impacts of changes in the final demand (Miller and Blair, 2009; Hawdon and Pearson, 1995; Kondo, Moriguchi, and Shimizu, 1998; Machado, Schaeffer, and Worrell, 2001; Liu et al., 2010).

Input-output structural decomposition analysis is a major analytical tool used to study the observed changes in the level and mix of output. The basic rationale for input-output structural decomposition analysis is splitting an identity into its components (Rose and Casler, 1996). The application of structural decomposition analysis is aimed at identifying the driving factors for change in key variables over time (Casler and Rose, 1998; Ang and Liu, 2001; Wood and Lenzen, 2009). The first formal decomposition of the sources of change in air pollution emissions known to us is performed by Leontief and Ford in 1972. After Leontief's pioneering work, energy analysis has been focused on structural decomposition analysis investigation (Chen and Rose, 1990; Rose and Chen, 1991), and has examined the mix of output

[3]There are three kinds of impacts on the environment and on natural resources related to international trade: scale, composition and technical effects (OECD, 1997; Nordströmm and Vaughan, 1999).

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(Pløger, 1984), technology and demand change (Gowdy and Miller, 1987). Extension of SDA to carbon dioxide emission analysis has since become a popular field of study (e.g., Casler and Rose (1998); Liu and Ang (2007); Wood and Lenzen (2009); Liu et al. (2010)).

3 The Effect of Carbon Tax on CO_2 Emissions

Most economists and international organizations have recommended carbon taxes as a cost-effective instrument for reducing CO_2 emissions. Once the tax rate has been set, emissions-intensive goods will have higher market prices and/or lower profits (Baranzini, Goldemberg, and Speck, 2000). Some researchers estimated the impact of carbon taxes with the different settings of tax rates on global CO_2 emissions (Nordhaus, 1990; Manne and Richels, 1990; Whalley and Wigle, 1991). All of their results showed that the mitigating effects of carbon taxes are significant. Aasness, Bye, and Mysen (1996) found that a carbon tax rate of \$65 per ton of CO_2 could let Norway's CO_2 emissions stay at the 1989 level in 2020 through the general equilibrium approach. Symons, Proops, and Gay (1994) simulated levying carbon taxes in Britain. The result indicated that carbon taxes would affect the price of fossil fuels, consumer price, and the level and structure of the UK's final demand. Nakata and Lamont (2000), applying the partial equilibrium method, found that carbon and energy taxes would reduce CO_2 emissions to achieve their mitigation goal. It would also encourage the use of gas instead of coal. Wissema and Dellink (2007) found that levying of carbon tax could also promote the development of renewable energy. Siriwardena et al. (2007) examined the total extent of CO_2 mitigation using different levels of price elasticity of demand, and considered the case of Sri Lanka's energy and carbon taxes. Using this simulation, they are able to calculate the most effective carbon tax rate to reduce using carbon-intensive products. Lu, Tong, and Liu (2010) found that carbon taxes could cut down the carbon emissions in China with the dynamic general equilibrium model, and it is effective with minimal impact on GDP.

However, the claim that carbon taxes reduce CO_2 emissions is controversial. Other studies show that the mitigating effects of carbon taxes are insignificant due to the tax exemption policies in certain energy intensive industries (Lin and Li, 2011; Bohlin, 1998). Carbon taxes would induce an unbalanced burden on industries in countries across Europe (Bordigoni, Hita, and Blanc, 2012). Morgenstern et al. (2004) looked at the impacts

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of a carbon emissions reduction policy on manufacturing industries in the United States. They found that variations of the tax effect among industries are large which may be caused by very different tax policies. Furthermore, the simulation yielded a greater mitigation effect when there's no tax exemption or tax revenue redistribution (Liang, Fan, and Wei, 2007). Nevertheless, if we remove carbon tax exemptions, this may lead to rising levels of global emissions. It may also influence foreign trade and even social welfare (Harrison and Kriström, 1997; Baranzini, Goldemberg, and Speck, 2000).

Based on the results of existing studies, the effect of carbon taxes on the international competitiveness of industries is still controversial. Hence, it is urgent that Taiwan learn more about energy embodied in exports, and the structure of energy-intensive products or energy efficiency, etc. so that we can reinforce our energy mitigation policies.

4 Methodology

4.1 Energy Input-Output Analysis

Wassily Leontief integrated the concept of the interaction between industries and the general equilibrium theory into the input-output analysis. It has been commonly used to analyze the energy embodied in goods and services and factors causing the changes of energy embodied in industries (Casler and Hannon, 1989; Wu and Chen, 1990; Kagawa and Inamura, 2001; Pan, Phillips, and Chen, 2008; Lu, Tong, and Liu, 2010).

In the input-output model, total output of an economy is the sum of the intermediate requirements and the final demand of the economy. Let X represents the total output (column) vector, A represent the input coefficients matrix, AX is then the sum of the intermediate demand. With Y being the final demand (column) vector, the following relationship holds (Leontief, 1970):

$$X = AX + Y = (I - A)^{-1}Y = LY, \tag{1}$$

where $(I - A)^{-1}$ is the Leontief inverse matrix.

The objective of this paper is to analyze the interaction between energy and the economy. However, if we continue using the original input-output model which uses a standard monetary unit to express the condition of industries' energy input, it may have the following drawbacks:

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1. Energy prices are highly unstable. Hence, when there are extreme fluctuations in energy prices, we will not be able to get the actual energy demand of industries under the original model with the standard monetary units (Chang and Lin, 1998).
2. Using the model with monetary units may not be able to meet the desired level of energy conservation when calculating industries' energy input (Chen and Rose, 1990).

This paper adopts the hybrid-unit input-output model developed by Bullard and Herendeen (1975) to calculate the energy/carbon intensity, which is energy/carbon consumption per unit of total output of the economy. Under the hybrid-unit input-output analysis, all industrial sectors of the economy are separated into energy sectors and non-energy sectors. The former is represented by a physical unit, and the latter is represented by a monetary unit (Bullard and Herendeen, 1975; Bullard, Penner, and Pilati, 1978; Miller and Blair, 2009; Park and Heo, 2007).

In the hybrid-unit input-output model, we can define the new transactions matrix Z^*, total output vector X^*, and final demand vector Y^*. The corresponding matrices are as follows:

$$A^* = Z^* \left(\hat{x}^*\right)^{-1}, \tag{2}$$

$$L^* = \left(I - A^*\right)^{-1}, \tag{3}$$

where any element in A^* is the direct energy/carbon input per unit of total output, elements in Z^* are interindustry transactions, and $(\hat{X}^*)^{-1}$ is the inverse of the diagonalized matrix whose diagonal elements are total output. L^* is the total energy/carbon input per unit of total output. Therefore, total energy/carbon intensity (α) can be expressed as follows:

$$\alpha = G \left(\hat{x}^*\right)^{-1} L^*, \tag{4}$$

where G is the total output of energy sectors and it is nonzero only for energy sectors. While $G(\hat{x}^*)^{-1}$ is a tool for isolating the energy rows.

4.2 Input-Output Structural Decomposition Analysis

There are a variety of reasons causing the fluctuation of a country's indirect energy exportation, such as the growth in the exportation, changes in the international trade structure, technology progression, and energy efficiency

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advancement (Hoekstra and van den Bergh, 2002; Liu and Ang, 2007). In this paper, we use the input-output structural decomposition analysis (SDA) to identify five factors which have contributed to the changes in the energy embodied in exports over time (Wood and Lenzen, 2009; Liu et al., 2010).

The changes in the energy embodied in exports (ΔE^{ex}) for sectors can be decomposed into the changes in total energy intensities ($\Delta\alpha$) and changes in exports (ΔY^{ex}), as follows:

$$\begin{aligned}\Delta E^{ex} &= E_t^{ex} - E_{t-1}^{ex} \\ &= \alpha_t Y_t^{ex} - \alpha_{t-1} Y_{t-1}^{ex} \\ &= \left(\alpha_t Y_t^{ex} - \alpha_{t-1} Y_{t-1}^{ex}\right) - \alpha_{t-1} Y_t^{ex} + \alpha_{t-1} Y_t^{ex} \\ &= (\alpha_t - \alpha_{t-1})\, Y_t^{ex} + \alpha_{t-1}\left(Y_t^{ex} - Y_{t-1}^{ex}\right) \\ &= \Delta\alpha Y_{t-1}^{ex} + \alpha_t \Delta Y^{ex}. \end{aligned} \tag{5}$$

We can find that structure decomposition is additive and non-unique, and it does not include interaction terms. Therefore, we use the simple average of only two decomposition forms, polar forms (Dietzenbacher and Los, 1998; Miller and Blair, 2009), to solve the non-uniqueness problem. The changes in the energy embodied in exports are then as follows:

$$\Delta E^{ex} = \frac{1}{2}(\Delta\alpha)\left(Y_t^{ex} + Y_{t-1}^{ex}\right) + \frac{1}{2}(\alpha_t + \alpha_{t-1})\left(\Delta Y^{ex}\right). \tag{6}$$

We can use this same method to decompose other fluctuating factors. The changes in the total energy intensities ($\Delta\alpha$) can be decomposed into the changes in direct energy intensities (Δe) and the Leontief inverse (ΔL).

$$\begin{aligned}\Delta\alpha &= e_t L_t - e_{t-1} L_{t-1} \\ &= \Delta e L_{t-1} + e_t \Delta L \\ &= \frac{1}{2}(\Delta e)\,(L_t + L_{t-1})\,\frac{1}{2}\,(e_t + e_{t-1})\,(\Delta L). \end{aligned} \tag{7}$$

The changes in the Leontief inverse (ΔL) can be further decomposed into the changes in the direct input-coefficients (ΔA_t). ΔA_t can also represent the change effects of the structure of intermediate inputs.

$$\begin{aligned}\Delta L &= L_t - L_{t-1} \\ &= (I - A_t)^{-1} - (I - A_{t-1})^{-1} \\ &= L_t\left[(I - A_{t-1}) - (I - A_t)\right] L_{t-1} \end{aligned}$$

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$$= L_t \left(A_t - A_{t-1}\right) L_{t-1}$$
$$= L_t \left(\Delta A_t\right) L_{t-1}. \tag{8}$$

The structure of exports (F^{ex}) can be expressed as follows:

$$F^{ex} = \frac{Y_i^{ex}}{\Sigma Y_i^{ex}}, \tag{9}$$

where Y_i^{ex} represents the export of the i sector.

Hence, the changes in exports can be decomposed into the changes in the total volume of exports (ΔY_s^{ex}) and the structure of exports (ΔF^{ex}).

$$\begin{aligned}\Delta Y^{ex} &= Y_t^{ex} - Y_{t-1}^{ex} \\ &= Y_{s,t}^{ex} F_t^{ex} - Y_{s,t-1}^{ex} F_{t-1}^{ex} \\ &= \Delta Y_s^{ex} F_t^{ex} + Y_{s,t-1}^{ex} \Delta F^{ex} \\ &= \frac{1}{2}\left(\Delta Y_s^{ex}\right)\left(F_t^{ex} + F_{t-1}^{ex}\right) + \frac{1}{2}\left(Y_{s,t}^{ex} + Y_{s,t-1}^{ex}\right)\left(\Delta F^{ex}\right). \end{aligned} \tag{10}$$

Direct energy intensity can be expressed (e) as follows:

$$e = \text{diag}\left(e_s\right)\left(\text{diag}\left(e_s\right)^{-1}\right) e = \text{diag}\left(e_s\right) R, \tag{11}$$

where diag (e_s) can also be expressed as $\hat{e}_s$, e_s is the sum of direct energy intensity over all industries, and R is the energy intensity share matrix.

The changes in direct energy intensities (Δe) can be decomposed into the changes in the energy consumption level (Δe_s) and the structure of the energy consumption (ΔR):

$$\begin{aligned}\Delta e &= e_t - e_{t-1} \\ &= \hat{e}_{s,t} R_t - \hat{e}_{s,t-1} R_{t-1} \\ &= \Delta \hat{e}_s R_t + \hat{e}_{s,t-1} \Delta R = \Delta \hat{e}_s R_{t-1} + \hat{e}_{s,t} \Delta R \\ &= \frac{1}{2}\left(\Delta \hat{e}_s\right)\left(R_t + R_{t-1}\right) \frac{1}{2}\left(\hat{e}_{s,t} + \hat{e}_{s,t-1}\right)\left(\Delta R\right). \end{aligned} \tag{12}$$

As suggested by Dietzenbacher and Los (1998), using the average of two polar forms (as in (12)) is often an acceptable approach, because using other approaches will inevitably create additional "interaction" terms, which are usually very difficult to interpret their economic meanings.

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Finally, we combined all the separate parts and obtained the following equation for the decomposition of the energy embodied in exports:

$$\begin{aligned}\Delta E^{ex} = {} & 1/8\left(\Delta\hat{e}_s\right)\left(R_t + R_{t-1}\right)\left(L_t + L_{t-1}\right)\left(Y_t^{ex} + Y_{t-1}^{ex}\right) \\ & + 1/8\left(\hat{e}_{s,t} + \hat{e}_{s,t-1}\right)\left(\Delta R\right)\left(L_t + L_{t-1}\right)\left(Y_t^{ex} + Y_{t-1}^{ex}\right) \\ & + 1/4\left(e_t + e_{t-1}\right)L_t\left(\Delta A_t^*\right)L_{t-1}\left(Y_t^{ex} + Y_{t-1}^{ex}\right) \\ & + 1/4\left(\alpha_t + \alpha_{t-1}\right)\left(\Delta Y_s^{es}\right)\left(F_t^{ex} + F_{t-1}^{ex}\right) \\ & + 1/4\left(\alpha_t + \alpha_{t-1}\right)\left(Y_{s,t}^{ex} + Y_{s,t-1}^{ex}\right)\Delta F^{ex}. \end{aligned} \tag{13}$$

According to the above decomposition, the changes in the energy embodied in exports are caused by the following factors. The changes in the direct energy use of each industry can be shown in the first term on the right-hand side of Eq. (13) and which indicate that the changes in the energy efficiency of industries. The second term of that equation is shown that the fluctuation of the share of each energy used directly in each industry which indicate the changes in the structure of energy consumption of industries. The third term shows that the changes in the structure of intermediate inputs for each industry. Then, the fourth term shows that the fluctuation of total volume of exports of industries. Finally, the fluctuation of the share of export volume for each industry to the total export volume for the whole economy can be shown in fifth term which represents that the changes in the structure of exports.

4.3 Carbon Tax Analysis

In the input-output price model, we assume that the price of each product is expressed as an index. In other words, the base year price of each sector is expressed as a percentage. According to the assumption of input-output analysis, the sum of the supply is equal to the sum of the demand. Hence, the market price of commodities (p_j) is the sum of the input cost (Lee, 2005), as follows:

$$\begin{aligned} & a_{11}p_1 + a_{21}p_2 + \cdots + a_{n1}p_n + v_1 = p_1 \\ & a_{12}p_1 + a_{22}p_2 + \cdots + a_{n2}p_n + v_2 = p_2 \\ & \quad\vdots \qquad\qquad \vdots \qquad\qquad \vdots \\ & a_{1n}p_1 + a_{2n}p_2 + \cdots + a_{nn}p_n + v_n = p_n, \end{aligned} \tag{14}$$

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where a_{ij} is the input coefficient, v_j is the primary input coefficient (value added per unit). We divide the above equations by the commodity prices (p_j) on the right-hand side and arrive at the equation ($\Sigma_i a_{ij} + a_j^v = 1$) represented as the total output, which is equal to the sum of the intermediate inputs and the primary inputs.

The imposition of the carbon tax would cause the commodity's price to increase and then may indirectly cause the change in the input coefficients. This research referred to previous studies to simulate the fluctuation after the tax imposition with Sweden tax rates ($22.2 U.S. dollars/$CO_2$ per ton) (Liang, 2009; Yang, 2009). We used this carbon tax rate with Leontief price model to calculate the changes in the commodity price after taxation. On the other hand, we also have to count on energy's price elasticity of demand with the assumption of fix-total output in order to calculate the changes in the production quantity of industries.

The primary goal of this section is to measure the energy-demand relationship to revise the input coefficients of the model after taxation. The methodology of the elasticity estimation referred to the study of Houthakker, Philip K. Verleger, and Sheehan (1974), the model is as follows:

$$Q_t^D = Q_{t-1}^D \gamma + X_t \beta + X_{t-1} \alpha + \varepsilon_t, \tag{15}$$

where Q_t^D is log energy demand in year t, Q_{t-1}^D is the lag value of log energy demand, X_t is a set of measured covariates (e.g. energy prices, population, income, and climate) that affect energy demand, X_{t-1} is the lag values of the covariates, and ε_t is a random error term. The application study of Bernstein and Griffin (2006) sets demand as a function of prices, income, population and climate, as follows:

$$Q_t^{D^*} = f\left(P_t, Y_t, \text{Pop}_t, \text{Climate}_t\right), \tag{16}$$

where $Q_t^{D^*}$ denotes desired demand in year t. Empirically, due to the possible non-stationarity property of the variables and the potential cointegrating relationships existing among them, we conducted unit root and cointegration tests to obtain the long-run price elasticity measures for our further analysis.[4] Please see Table A3-A6 for the variable and data used for estima-

[4]In this study, we applied the long-run price elasticity to measure the effects of price change on quantity demand. The reasons are: (1) input-output tables are annual estimates of the transaction flows of the economy, and the tables we used are those at producers' prices, which are usually used to capture longer run effects; and (2) our carbon tax analysis is a comparative static one, which measures the completed effects of a policy change.

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tion, unit root test results, conintegration test results, as well as the elasticity estimates.

This study used the price elasticity of demand to adjust energy input coefficients in order to compute the changes in the energy use after taxation. We assumed that the prices of non-energy sectors were unchanged and the energy use is normally decreasing after tax imposition. Therefore, we combined the price elasticity of demand and the new commodity prices after taxation to figure out the fluctuation of industries' production quantities.

5 Results and Discussions

5.1 Data

Three sets of data are needed for our analysis: input-output tables, energy balance sheets, and CO_2 emission coefficients for energies. Input-output tables used in this study are those measured at producers' prices and were originally developed by The Directorate General of Budget, Accounting and Statistics (DGBAS) of Taiwan. The tables have 45, 49, and 52 sectors respectively for year 1996, 2001 and 2006. All the original tables are in current prices. For the purposes of this study, which intends to analyze the changes in energy and carbon embodied in exports, we need to convert the tables into constant-price tables. We set year 2006 as our benchmark year and convert the other two years' tables into 2006 prices tables.[5] To convert the tables into constant-price ones, we did it separately for domestic and import tables first, and then combine them together. The price indices used for domestic tables are sectoral output price indices, and the price indices for import ones are import price indices, all published by DGBAS. However, for primary sectors, construction, and service industry sectors, there have no published import price indices available. As such, we relied on sectoral output price indices to complete the conversion process.

In addition to converting all input-output tables into constant-price tables, we also need to convert the tables with monetary units into hybrid-unit tables, in which all energy inputs to all sectors are converted from monetary terms into numbers with physical units (BTU in this paper). In order to

[5]After initially converted the tables into constant-price tables, the tables would not be balanced. We further used RAS method to balance the tables. The boundary conditions used for performing RAS are that all column sums of intermediate demands are proportionally adjusted to make sure that the sum of all sums is exactly the same as the sum of all row sums.

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compile hybrid-unit input-output tables, we first match up the tables' sector classification with those of energy balance sheets and end up with a 33 sectors classification, which comprises 3 primary energy sectors (crude oil, coal, and natural gas), 2 secondary energy sectors (petroleum products and electricity) and 28 non-energy sectors. Then, we take the energy use data from the energy balance sheets to replace the monetary values in input-output tables.[6]

Energy balance sheets used in the construction of hybrid-unit input-output tables were developed by the Bureau of Energy (BOE), under the Ministry of Economic Affairs (MOEA) of Taiwan. After we have constructed our hybrid-unit input-output tables for 1996, 2001 and 2006, we are ready to perform energy input-output analysis and calculate the energy embodied in exports for Taiwan for the three years. However, to further calculate carbon embodied in exports, we need to convert the energy input numbers in the tables from BTU into the volume of CO_2 emissions, with the help of CO_2 emission coefficients for all energy types.[7] These coefficients are developed by the GHG[8] Emissions Registry of the Environmental Protection Administration (EPA), Taiwan.

5.2 Energy Embodied in Exports

According to the theory of energy input-output analysis presented in previous chapter, the direct and total energy intensities are the direct and total energy coefficients (A^* and L^*) in hybrid units respectively. The direct and total energy coefficients are the direct and total energy inputs per unit of total output of sectors.

The direct and total energy intensities of sectors for Taiwan in 1996, 2001 and 2006 shown in Table 1 are measured in 10^9 Kcal/Million dollars.[9] As shown in Table 1, for most of the sectors the average direct energy inten-

[6]When compiling hybrid-unit input-output tables, it is very important to distinguish between primary and secondary energy and not to double count the energy used by sectors. Basically, we follow the methodology mentioned in Miller and Blair (2009) to compile our hybrid-unit tables.

[7]In calculating the CO_2 emissions, we take into account only those used for generating energy, while those for non-energy uses are not considered here following the typical rules and steps suggested by EPA and BOE.

[8]This stands for greenhouse gases.

[9]As mentioned earlier, all results are in 2006 prices.

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Table 1: Direct and Total Energy Intensities of Non-Energy Sectors (10^9 Kcal/Million dollars)

Sectors	Direct			Total		
	1996	2001	2006	1996	2001	2006
Agriculture, Forestry	0.001	0.003	0.004	0.069	0.145	0.231
Fishing	0.139	0.105	0.071	0.531	0.555	0.874
Other ores	0.004	0.007	0.008	0.039	0.098	0.218
Food, Beverages, Tobacco	0.011	0.011	0.011	0.119	0.211	0.361
Fabric, Clothes, Accessory	0.031	0.034	0.031	0.307	0.567	0.936
Manufacture of Leather	0.011	0.016	0.010	0.160	0.326	0.554
Manufacture of Timber	0.007	0.006	0.007	0.116	0.215	0.368
Paper, Paper products, Print	0.036	0.028	0.024	0.268	0.392	0.553
Chemical materials	0.045	0.040	0.040	0.400	0.607	1.007
Manufacture of Rubber	0.018	0.016	0.013	0.300	0.519	0.755
Chemical products	0.019	0.026	0.020	0.259	0.459	0.757
Non-metal ores products	0.113	0.099	0.103	0.397	0.630	1.057
Metal	0.020	0.020	0.020	0.217	0.426	0.706
Metal products	0.008	0.008	0.009	0.175	0.349	0.525
Machinery	0.003	0.008	0.002	0.128	0.283	0.388
Electrical machinery and equipment	0.005	0.007	0.006	0.158	0.313	0.445
Transport equipment	0.003	0.005	0.005	0.126	0.267	0.388
Other manufacturing products	0.006	0.006	0.006	0.177	0.308	0.457
Building construction	0.002	0.002	0.001	0.144	0.241	0.424
Water	0.025	0.031	0.031	0.251	0.461	0.683
Transportation and Storage	0.180	0.170	0.149	0.549	0.680	1.674
Postal and Telecommunication services	0.006	0.003	0.003	0.070	0.080	0.190
Wholesale and Retail trades	0.002	0.002	0.002	0.039	0.065	0.101
Financial, Insurance services and Real estate	0.000	0.000	0.000	0.020	0.031	0.048
Hotel and Catering	0.018	0.020	0.021	0.086	0.158	0.326
Commerce services	0.001	0.000	0.001	0.062	0.075	0.153
Public administration services	0.010	0.009	0.008	0.076	0.103	0.169
Social, Personal, and Other services	0.010	0.014	0.010	0.095	0.212	0.263
Average carbon intensities	0.019	0.018	0.015	0.158	0.264	0.430

Source: Own calculation.

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sities of 28 non-energy sectors decreased continuously from 1996 to 2006. The average direct energy inputs is 0.019×10^9 Kcal per unit of total output of the Taiwanese economy in 1996, 0.018×10^9 Kcal per unit of total output in 2001 and down to 0.015×10^9 Kcal per unit of total output in 2006. On the contrary, the average total energy intensities of 28 non-energy sectors increased from 1996 to 2001, and increased again from 2001 to 2006. The total energy inputs is 0.158×10^9 Kcal per unit of total output in 1996, 0.264×10^9 Kcal in 2001 and 0.430×10^9 Kcal in 2006.

Direct energy intensity decreases and, at the same time, total energy intensity increases means that the economy is using less energy directly but consuming more energy indirectly. We can see from Table 1 that chemical materials, non-metal ores and products, and transportation and storage are the top three sectors with highest total energy intensities. Generally speaking, agricultural sectors and service sectors have lower total energy intensities, while manufacturing sectors have higher total energy intensities, which conform to our general intuition.

Using the energy intensity results obtained from the previous section, we are able to calculate the energy embodied in exports for each of the three years, 1996, 2001 and 2006. According to the results showed in Table 3, the energy embodied in exports are $805{,}684 \times 10^9$ Kcal in 1996, $1{,}886{,}031 \times 10^9$ Kcal in 2001 and $5{,}502{,}884 \times 10^9$ Kcal in 2006, respectively. Energy embodied in exports for Taiwan increased from 1996 to 2001, and then increased again from 2001 to 2006. Among those energy used in Taiwan, coal has increased most significantly from 1996 to 2006.

The SDA models presented in the previous section are then applied to analyze the relative contributions of factors that are responsible for the changes in energy embodied in exports during the two sub-periods between 1996 and 2006. Results of structural decomposition are shown in Table 2. As revealed in Table 2, the total increment of the energy embodied in exports during 1996 to 2001 is $1{,}080{,}346 \times 10^9$ Kcal. Among the five factors, changes in the structure of intermediate inputs and the structure of exports are the major factors that have contributed to the change of energy embodied in exports, and the accumulated changes are 42.39% and 39.59%, respectively. The changes in total volume of exports showed to decrease the energy embodied in exports, and the accumulated change is −2.74%. This is because that a significant decline in economic outputs was encountered in 2001 and so did the exports. Moreover, changes in the direct energy efficiency and energy consumption structure have contributed 12.25% and

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Table 2: SDA Results of Changes in Energy Embodied in Exports

(Unit: 10^9 Kcal)	1996–2001	2001–2006
Direct energy efficiency	132,382	163,472
	(12.25%)	(4.52%)
Structure of energy consumption	91,879	26,965
	(8.50%)	(0.75%)
Structure of intermediate inputs	457,959	1,701,901
	(42.39%)	(47.06%)
Structure of export	427,740	1,586,510
	(39.59%)	(43.86%)
Total volume of export	−29,614	137,965
	(−2.74%)	(3.81%)
Total increment	1,080,346	3,616,813
	(100.00%)	(100.00%)

Table 3: Energy Embodied in Exports, 1996–2006

(Unit: 10^9 Kcal)	1996	2001	2006
Oil	276,065	353,792	652,377
Coal	229,381	1,070,207	3,737,260
Gas	22,055	59,650	224,644
Petroleum	206,156	259,016	404,800
Electricity	72,027	143,366	483,762
Total	805,684	1,886,031	5,502,844

8.50% to the accumulated changes, respectively.

Also from Table 2, the total increment of the energy embodied in exports during the period 2001 to 2006 is $3{,}616{,}813 \times 10^9$ Kcal. Contrary to the first sub-period, all factors showed to increase the energy embodied in exports. Changes in the structure of intermediate inputs and the structure of exports are still the major factors that contributed to the change of energy embodied in exports, and the accumulated changes are 47.06% and 43.86%, respectively. Moreover, it is also very interesting to see from Table 2 that, the change in energy consumption structure has contributed 8.5%

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to the accumulated changes of energy embodied in export during the first sub-period, but only 0.75% during the second sub-period.

For both the two sub-periods, our results show that the contribution of direct energy efficiency and structure of intermediate inputs have contributed to reduce the energy embodied in exports, indicating that energy efficiency has improved and production of industries has been changed towards using more energy-saving technologies in Taiwan. Nevertheless, the contributions of the structure of exports and total volume of exports have shown to increase the energy embodied in exports. In particular, the changes in the structure of exports for the two periods have had a big effect on energy embodied in exports for Taiwan.

While the total increment of energy embodied in exports in the second period (2001 to 2006) is more than 3 times that of the first period (1996 to 2001), and the changes in the structure of exports is demonstrated to be the most important factor that has contributed to this change, it would be needed to check further which sectors are the most responsible ones. To this end, we examined the structure of exports for the three years, together with the results of total energy intensity of sectors, to figure out the major sectors causing the change in the energy embodied in exports As shown in Table 4, the electrical machinery and equipment and the chemical materials sectors are the two sectors that have significant changes in the share of exports of the economy. Although the total energy intensity of the former sector is not among the highest, the latter has already been shown to be one of the most important sectors with high total energy intensity.

5.3 Carbon Embodied in Exports

Similar to energy input-output analysis, we perform our carbon embodied in exports and SDA analysis based on the theory described in previous sections. With the hybrid-unit environmental input-output tables, the direct and total carbon intensities are the direct and total carbon coefficients (A^* and L^*) in hybrid units respectively. The direct and total carbon coefficients are shown as the direct and total carbon input of per unit of total output of sectors. The results of direct and total carbon intensities of industries for Taiwan in 1996, 2001 and 2006, shown in tons/Million dollars,[10] are

[10]Again, all results are in 2006 prices. It is very important to know that the CO_2 emissions attributable to Taiwan's exports for a particular year might not be the numbers shown in the tables. As a recently developed approach by Wang, Wei, and Zhu (2013) suggests, due to the

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Table 4: Structure of Exports in Taiwan, 1996–2006

(Unit: Percent)	1996	2001	2006
Agriculture, Forestry	0.18	0.10	0.06
Fishing	0.80	0.86	0.42
Oil	0.00	0.00	0.00
Coal	0.00	0.00	0.00
Natural gas	0.00	0.00	0.00
Petroleum	0.78	1.63	4.10
Electricity	0.01	0.01	0.00
Other ores	0.04	0.02	0.02
Food, Beverages, Tobacco	2.02	0.70	0.39
Fabric, Clothes, Accessory	9.40	6.72	3.28
Manufacture of Leather	0.90	0.51	0.37
Manufacture of Timber	1.01	0.60	0.23
Paper, Paper products, Print	0.80	0.66	0.61
Chemical materials	3.83	7.13	7.61
Manufacture of Rubber	4.43	2.91	2.56
Chemical products	1.84	1.62	1.11
Non-metal ores products	0.81	0.72	0.38
Metal	2.79	5.18	5.04
Metal products	5.03	5.27	3.72
Machinery	6.33	5.61	5.33
Electrical machinery and equipment	32.56	35.15	42.01
Transport equipment	3.93	2.89	2.99
Other manufacturing products	4.97	2.79	2.83
Building construction	0.10	0.08	0.00
Water	0.00	0.00	0.00
Transportation and Storage	7.15	6.18	4.75
Postal and Telecommunication services	0.53	0.27	0.13
Wholesale and Retail trades	5.12	7.86	8.88
Financial, Insurance services and Real estate	0.38	0.50	0.35
Hotel and Catering	1.42	1.36	0.82
Commerce services	1.89	1.61	0.73
Public administration services	0.00	0.00	0.12
Social, Personal, and Other services	0.95	1.08	1.13

Source: Input-output tables, various years, DGBAS.

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presented in Table 5.[11]

As shown in Table 5, for most of the sectors the average direct carbon intensities of 28 non-energy sectors increased from 1996 to 2001, but decreased from 2001 to 2006. The average direct carbon embodied is 5.07 tons per unit of total output of the Taiwanese economy in 1996, 5.96 tons per unit of total output in 2001 and down to 5.24 tons per unit of total output in 2006. On the contrary, the average total carbon intensities of 28 non-energy sectors increased from 1996 to 2001, and increased again from 2001 to 2006. The total carbon embodied is 45.91 tons per unit of total output in 1996, 121.64 tons per unit of total output in 2001 and 164.06 tons per unit of total output in 2006.

Finally, we can see from Table 5 that chemical materials, non-metal ores and products, and transportation and storage are the top three sectors with highest total carbon intensities. Just like the results of energy input-output analysis, agricultural sectors and service sectors have lower while manufacturing sectors have higher total carbon intensities, which also conform to our general intuition.

Using the carbon intensity results obtained from the previous section, we are able to calculate the carbon embodied in exports for each of the three years, 1996, 2001 and 2006. According to the results shown in Table 7, the carbon embodied in exports are 268.54 million tons in 1996, 697.98 million tons in 2001 and 2,103.17 million tons in 2006, respectively. Carbon embodied in exports for Taiwan increased from 1996 to 2001, and then increased again from 2001 to 2006. Among those energy that emit CO_2 in Taiwan, coal has increased significantly from 1996 to 2006. The SDA models are then applied to analyze the relative contributions of factors that are responsible for the changes in carbon embodied in exports during the two sub-periods between 1996 and 2006. Results of structural decomposition

significant increase in intermediate trade, the proportion of domestic value added embodied in exports has been decreasing. According to Dinh (2015) recent research results for Taiwan, the proportion of domestic value added embodied in exports has decreased from 66.63% in 1995 to 52.24% in 2011. Readers are advised to take this into account when interpreting our results. Readers are also suggested to consult the detailed proportions for each sector as shown in Table A2 in the Appendices.

[11] Table A1 in Appendices shows the sectoral exports and carbon emissions for all three years. As shown in the table, electrical machinery and equipment is the most important exporting sector for Taiwan, while Transportation and Storage sector is the sector emitting most carbon dioxide in Taiwan.

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Table 5: Direct and Total Carbon Intensities of Non-Energy Sectors (Ton/Million NTD)

Sectors	Direct			Total		
	1996	2001	2006	1996	2001	2006
Agriculture, Forestry	0.31	1.06	1.39	18.62	60.99	82.84
Fishing	22.10	32.86	22.45	84.94	213.47	325.51
Other ores	1.34	2.45	2.83	12.22	44.36	82.01
Food, Beverages, Tobacco	3.23	3.54	3.74	35.53	91.62	135.40
Fabric, Clothes, Accessory	9.46	11.35	10.28	106.67	259.12	355.25
Manufacture of Leather	2.97	5.30	5.13	47.67	148.45	223.79
Manufacture of Timber	2.16	2.55	2.51	37.06	117.39	140.74
Paper, Paper products, Print	10.31	9.93	8.71	73.11	175.46	211.01
Chemical materials	14.22	17.37	14.92	119.48	334.26	392.03
Manufacture of Rubber	4.98	5.60	5.44	82.77	253.38	319.97
Chemical products	5.47	8.71	5.13	77.56	223.12	254.64
Non-metal ores products	32.73	36.95	38.67	116.02	303.60	408.94
Metal	5.51	7.39	7.29	62.00	200.93	271.22
Metal products	2.42	2.85	3.23	50.73	161.40	200.76
Machinery	1.01	2.43	0.71	40.50	127.61	148.00
Electrical machinery and equipment	1.52	2.42	2.23	47.46	147.08	173.08
Transport equipment	0.98	1.59	1.74	36.98	129.93	148.63
Other manufacturing products	1.80	1.80	2.11	52.27	144.44	177.27
Building construction	0.50	0.55	0.33	40.11	112.20	161.82
Water	7.76	11.65	11.39	76.02	206.96	265.06
Transportation and Storage	39.73	51.20	45.49	119.98	244.99	614.85
Postal and Telecommunication services	1.15	1.09	1.21	12.18	32.40	69.11
Wholesale and Retail trades	0.60	0.80	0.59	12.82	28.59	37.68
Financial, Insurance services and Real estate	0.13	0.18	0.15	6.45	14.55	17.73
Hotel and Catering	5.33	5.99	6.20	28.71	65.38	122.27
Commerce services	0.21	0.26	0.31	20.49	48.65	52.87
Public administration services	3.24	2.95	2.66	26.17	43.38	63.85
Social, Personal, and Other services	3.88	3.53	3.66	35.22	71.55	101.61
Average carbon intensities	5.07	5.96	5.24	45.91	121.64	164.06

Source: Own calculation.

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Table 6: SDA Results of Changes in Carbon Embodied in Exports

(Unit: Million tons CO_2)	1996–2001	2001–2006
Direct energy efficiency	65.26 (15.20%)	110.35 (7.85%)
Structure of energy consumption	26.94 (6.27%)	−33.23 (−2.37%)
Structure of intermediate inputs	184.68 (43.00%)	677.19 (48.19%)
Structure of export	152.79 (35.58%)	586.38 (41.73%)
Total volume of export	-0.22 (-0.05%)	64.50 (4.59%)
Total increment	429.44 (100.00%)	1,405.19 (100.00%)

Table 7: Carbon Embodied in Exports, 1996–2006

(Unit: Million tons CO_2)	1996	2001	2006
Oil	80.46	108.57	200.21
Coal	93.98	442.80	1,546.31
Gas	5.08	14.01	52.76
Petroleum	62.36	78.90	123.31
Electricity	26.66	53.69	180.58
Total	268.54	697.98	2,103.17

are shown in Table 6.

As revealed in Table 6, the total increment of the carbon embodied in exports during 1996 to 2001 is 429.44 million tons. Among the five factors, the structure of intermediate inputs and the structure of exports are the major factors that have contributed to the change of carbon embodied in exports, and the accumulated changes are 43.00% and 35.58%, respectively. Also from Table 6, the changes in total volume of exports revealed to decrease the carbon embodied in exports, and the accumulated change is −0.05%. Moreover, it is also very interesting to see from Table 6 that, the change in energy consumption structure has contributed 6.27% to the changes in carbon embodied in exports during the first sub-period. How-

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ever, this contribution significantly reduced to −2.37% in the second sub-period, indicating that energy consumption structure has evolved toward consuming less energy in the second sub-period.

It can also be seen from Table 6, the total increment of the carbon embodied in exports during the period 2001 to 2006 is 1,405.19 million tons. Contrary to the first sub-period, the export volume shown to increase the carbon embodied in exports. Changes in the structure of intermediate inputs and the structure of exports are still the major factors that have contributed to the change of carbon embodied in exports, and the accumulated changes are 48.19% and 41.73%, respectively.

Comparing with the results for the two sub-periods, we can see that direct energy efficiency, energy consumption structure, and structure of intermediate inputs have contributed to the decrease of the carbon embodied in exports and this indicates that energy efficiency, low carbon energy development, and production technology of Taiwan have all improved which have led the economy towards using less energy and, hence, less CO_2 emissions. However, the structure of exports and total volume of exports have shown to have negative effect on the carbon embodied in exports. In particular, the changes in the structure of exports for the two periods have had a big effect on carbon embodied in exports for Taiwan.

While the total increment of carbon embodied in exports in the second period (2001 to 2006) is about 3 times that of the first period (1996 to 2001), and the changes in the structure of exports is demonstrated to be the most important factor that has contributed to this change, it would be helpful to check further which sectors are most responsible. To this end, we can once again refer to the structure of exports (Table 4). We can see from the table that the electrical machinery and equipment and the chemical materials sectors are the two sectors that have significant changes in the share of exports of the economy. Although the total carbon intensity of the former sector is not among the highest, the latter has already been shown to be one of the most important sectors with high total carbon intensity.

5.4 The Effect of Carbon Tax on Carbon Embodied in Exports

In this paper, we would also like to explore how government policy could reduce the energy and carbon embodied in exports and to what extent. The policy we are considering here is carbon tax. Levying carbon tax on energy use based on the carbon content of energies will discourage energy consump-

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tion, as the energy cost will go high for almost all sectors of the economy.[12]

With regard to the level of the carbon tax, we refer to the Sweden carbon tax rate ($22.2 US dollars/ton CO_2) and apply it to the use of primary energy for all sectors. We then use Leontief price model to calculate the changes in the prices of outputs of all sectors after taxation. We would expect that imposing carbon tax will lead to an increase in prices for all sectors' outputs.

With the results of price changes for all sectors, we then need to calculate how these changes will change the direct usage of energy by sectors in their production process. To this end, we make use of the price elasticities of energy demand for all energy types.[13]

Using the percentage change in energy prices together with the price elasticities of energy demand for all energy types, we can calculate, under the assumption that sectoral outputs remain constant, the changes in energy inputs by sectors. When total output remains constant and energy input reduces, the input coefficient of energy for sectors will reduce. This result, combined with the assumption that other non-energy input coefficients and export levels remain constant, will lead to a results that the production levels of sectors will decline.

After tax imposition, the cost of manufacturers will increase, which will depress their production levels. The comparisons of total outputs with and without taxation are shown in Table 8. The change in total outputs with taxation for the whole economy in 1996 is −29,871 million NTD. In 2001, the figure is −130,140 million NTD and in 2006 it becomes −226,713 million NTD. These results indicate that the total outputs will be decreasing

[12]When the government decides to tax on energy use to comply with international climate change agreements, expectations arise and agents of the economy will try to adjust beforehand by changing their production and consumption behavior. With these expectations, the results of taxing on energy use might not exactly the same as we analyzed, unless we could incorporate expectation behavior into our models. Input-output SDA, being a static analysis is not suitable to specify the expectation behavior directly into the models. This limitation might thus cause our results to be slightly overestimated.

[13]We estimated the price elasticities of demand for oil, coal, natural gas, electricity, and refined petroleum products for Taiwan, and the data description and estimate results can be found in Table A3, A4, A5, and A6. As can be found in Table A6, some estimates of price elasticity are not significant (ex. Natural gas). As such, when applying the elasticities to our calculation of effects we might slightly overestimate the effects. Readers are advised to take this into account when interpreting the results.

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Table 8: Outputs with and without Carbon Tax

(Unit: Million NTD)	1996	2001	2006
Before tax	16,486,630	20,669,308	26,910,831
After tax	16,456,759	20,539,168	26,684,117
Total increment	−29,871	−130,140	−226,713

Table 9: Carbon Embodied in Exports with and without Carbon Tax

(Unit: Million tons CO_2)	1996	2001	2006
Before tax	268.54	697.98	2,103.17
After tax	243.10	494.94	1,290.60
total increment	−25.44	−203.04	−812.57

from 1996 to 2006 shall the economy impose a carbon tax to the production of goods and services. Furthermore, the effects of taxation for the period 2001 to 2006 will be smoother than those of the period 1996 to 2001.

As this paper is focusing mainly on analyzing the possible effects of carbon embodied in exports, we further compare the results on carbon embodied in exports for the cases. The results are shown in Table 9 below. Our results reveal that the total carbon embodied in exports will decline when levying the carbon tax on CO_2 emissions of industries. Even with the assumption of fixed-final demand, the changes in carbon embodied in exports will also decrease. If we further adjust the original exports volume according to the changes in total outputs, the decline of the carbon embodied in exports will be more significant.

The change of carbon embodied in exports with taxation is −25.45 million tons in 1996, −203.04 million tons in 2001 and −812.57 million tons in 2006. These results also indicate that the carbon embodied in exports will be decreasing from 1996 to 2006 shall the economy impose a carbon tax to the production of goods and services.

In addition to the above, we can also calculate the carbon embodied in exports for each of the three years, 1996, 2001 and 2006. As the results in Table 11 indicate, the carbon embodied in exports after taxation are 237.01 million tons in 1996, 485.70 million tons in 2001 and 1,248.56 million tons in 2006, respectively. Carbon embodied in exports after taxation still

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Table 10: SDA Results of Factors in Carbon Embodied in Exports with Carbon Tax

(Unit: Million tons CO_2)	1996–2001	2001–2006
Direct energy efficiency	33.58 (13.50%)	84.58 (11.09%)
Structure of energy consumption	11.31 (4.55%)	−38.36 (−5.03%)
Structure of intermediate inputs	86.51 (34.79%)	303.78 (39.82%)
Structure of export	116.32 (46.77%)	369.26 (48.41%)
Total volume of export	0.97 (0.39%)	43.59 (5.71%)
Total increment	248.69 (100.00%)	762.86 (100.00%)

Table 11: Carbon Embodied in Exports with Carbon Tax

(Unit: Million tons CO_2)	1996	2001	2006
Oil	71.55	91.47	162.57
Coal	80.55	269.46	805.47
Gas	4.75	12.58	42.87
Petroleum	55.28	64.69	92.83
Electricity	24.87	47.50	144.82
Total	237.01	485.70	1,248.56

matches the previous trend which increased from 1996 to 2006. Among the energy emitting CO_2, coal has increased most significantly from 1996 to 2006. Comparing with the carbon embodied in exports before taxation, CO_2 emissions of each year all decrease when imposing carbon tax. In order to see the responsible factors that contribute to the level of carbon embodied in exports after levying carbon tax, we decompose the change of carbon embodied in exports to analyze the relative contributions of factors that are responsible for the changes in carbon embodied in exports during the two sub-periods between 1996 and 2006. Results of structural decomposition are shown in Table 10.

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As revealed in Table 10, the total increment of the carbon embodied in exports after taxation during 1996 to 2001 is 248.69 million tons. Among the five factors, changes in the structure of intermediate inputs and the structure of exports are the major factors that have contributed to the change of carbon embodied in exports, and the accumulated changes are 34.79% and 46.77%, respectively. The change in total volume of exports is shown to increase slightly by 0.39%. Also from Table 10, the total increment of the carbon embodied in exports after taxation during the period 2001 to 2006 is 762.86 million tons. Contrary to the first sub-period, all factors shown to increase the carbon embodied in exports. Changes in the structure of intermediate inputs and the structure of exports are still the major factors that have contributed to the change of carbon embodied in exports, and the accumulated changes are 39.82% and 48.41%, respectively. Furthermore, the change in energy consumption structure has positive contribution to the changes in carbon embodied in exports during the first sub-period but negative during the second sub-period.

6 Conclusions

International trade is a major economic activity in Taiwan. While there is an increasing concern about climate change around the world and CO_2 has been one of the major greenhouse gases (GHG) causing global warming, having a good understanding of the energy and carbon embodied in trade is very important to the government agencies of Taiwan. This paper computed the energy and carbon intensities of the Taiwanese economy in 1996, 2001 and 2006 to figure out the changes of energy and carbon embodied in trade and their contributing factors. Our results show that the chemical materials, non-metal ore and products, and transportation and storage are the top three sectors with highest total carbon intensities. In particular, direct energy intensity decreases and, at the same time, total energy intensity increases means that the economy is using less energy directly but consuming more energy indirectly.

This paper also decomposed the changes into factors causing the changes in the energy and carbon embodied in exports. Among the five factors considered, changes in the structure of intermediate inputs and the structure of exports are the major factors that have contributed to the change of energy and carbon embodied in exports during 1996 to 2001. However, the changes in energy consumption structure has negative contribution to the

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changes in carbon embodied in exports during 2001 and 2006, indicating that the energy consumption structure in Taiwan had toward more clean energy structure during 1996 and 2006.

The changes in the structure of exports in 2001to 2006 is demonstrated to be the most important factor that has contributed to the changes in energy and carbon embodied in exports for that period. After examining the structure of exports, combined with the results for total energy and carbon intensity of sectors, we found that the electrical machinery and equipment and the chemical materials sector are the two sectors that have significant changes in the share of exports of the economy. Although the total energy and carbon intensity of the former sector is not among the highest, the latter has already been shown to be one of the most important sectors with high total carbon intensity.

The concept of sustainability has been well-taken all over the world. Therefore, the government should always find out the best way to achieve this goal. In this paper, we also explore how government policy could have reduced the energy and carbon embodied in exports and to what extent for Taiwan. Obviously, levying carbon tax on energy use based on the carbon content of energies will discourage energy consumption, as the energy cost will go high for almost all sectors of the economy. Our results show that the total outputs would decrease and the carbon embodied in exports would also decrease from 1996 to 2006. In addition, the SDA results of carbon embodied in exports after taxation conform to those without taxation between 1996 and 2006.

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Appendices

Table A1: Exports and Direct Carbon Emission of Non-Energy Sectors

Sectors	Export (Billion NTD in 2006 prices)			Direct Carbon Emission (Thousand tons CO_2)		
	1996	2001	2006	1996	2001	2006
1 Agriculture, Forestry	6	5	5	146	393	507
2 Fishing	29	44	35	3,306	2,731	1,941
3 Other ores	1	1	2	146	215	221
4 Food, Beverages, Tobacco	73	36	33	2,259	2,207	2,153
5 Fabric, Clothes, Accessory	340	342	272	6,287	6,841	5,147
6 Manufacture of Leather	32	26	31	186	204	175
7 Manufacture of Timber	36	30	19	209	170	168
8 Paper, Paper products, Print	29	34	50	3,596	3,035	3,121
9 Chemical materials	139	363	633	12,314	18,955	24,223
10 Manufacture of Rubber	160	148	213	2,124	2,224	2,091
11 Chemical products	67	82	92	1,655	2,390	2,059
12 Non-metal ores products	29	36	32	10,631	8,468	10,151
13 Metal	101	264	419	7,060	9,158	10,735
14 Metal products	182	268	310	1,532	1,721	2,214
15 Machinery	229	286	444	542	1,278	591
16 Electrical machinery and equipment	1,177	1,791	3,494	2,387	6,119	9,856
17 Transport equipment	142	147	249	545	723	1,066
18 Other manufacturing products	180	142	236	465	384	636
19 Building construction	4	4	0	669	624	415
20 Water	0	0	0	300	374	423

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Table A1: Exports and Direct Carbon Emission of Non-Energy Sectors (Cont.)

Sectors	Export (Billion NTD in 2006 prices)			Direct Carbon Emission (Thousand tons CO_2)		
	1996	2001	2006	1996	2001	2006
21 Transportation and Storage	258	315	395	35,133	39,755	44,836
22 Postal and Telecommunication services	19	14	11	239	412	491
23 Wholesale and Retail trades	185	401	739	1,008	1,616	2,010
24 Financial, Insurance services and Real estate	14	25	29	239	427	396
25 Hotel and Catering	51	69	68	1,234	1,851	2,874
26 Commerce services	68	82	60	93	179	312
27 Public administration services	0	0	10	2,972	2,998	3,204
28 Social, Personal, and Other services	34	55	94	5,682	7,188	8,940

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Table A2: Proportion of Domestic Value Added Embodied in Exports, by Sector

	1996	2001	2006	2011
Agriculture, Hunting, Forestry and Fishing	83.26	81.94	76.32	73.73
Mining and Quarrying	83.83	85.05	81.18	92.69
Food, Beverages and Tobacco	76.51	77.39	72.65	66.60
Textiles and Textile Products	70.94	75.17	68.62	64.24
Leather, Leather and Footwear	73.36	81.19	69.24	64.31
Wood and Products of Wood and Cork	64.43	65.24	63.27	61.62
Pulp, Paper, Paper , Printing and Publishing	72.98	72.60	65.58	63.86
Coke, Refined Petroleum and Nuclear Fuel	53.30	48.10	26.92	20.96
Chemicals and Chemical Products	63.12	60.77	48.12	49.17
Rubber and Plastics	69.23	69.98	57.76	54.71
Other Non-Metallic Mineral	77.67	74.18	65.37	58.10
Basic Metals and Fabricated Metal	68.82	68.81	55.35	49.84
Machinery, Nec	70.13	70.76	60.75	57.30
Electrical and Optical Equipment	57.90	56.51	49.11	51.06
Transport Equipment	70.84	71.10	61.67	59.57
Manufacturing, Nec; Recycling	75.57	81.92	65.29	60.14
Electricity, Gas and Water Supply	78.96	71.93	52.00	32.69
Construction	74.85	72.14	67.12	61.95
Wholesale and Retail Trade	95.85	93.82	93.93	93.72
Hotels and Restaurants	95.38	95.26	91.47	89.90
Transport	74.65	70.54	57.85	54.93
Other Services	88.49	87.07	85.80	84.60
Weighted average	**67.64**	**65.40**	**53.58**	**52.24**

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Table A3: Data Description and Sources for Elasticity Estimation

Variable	Description	Unit	Source
Q_OIL	Imported volume of crude oil	1000 barrels	Bureau of Foreign Trade (BOFT), Ministry of Economic Affairs
Q_GAS	Imported volume of liquid natural gas	1000 m^3	BOFT
Q_COAL	Imported volume of coal	metric ton (mt)	BOFT
Q_PETRO	Refined petroleum products consumption	KLOE	Bureau of Energy (BOE), Ministry of Economic Affairs
Q_ELEC	Electricity consumption	Million kWh	BOE
P_OIL	Imported crude oil price	NT$/barrel	BOFT
P_GAS	Imported gas price	NT$/$m^3$	BOFT
P_COAL	Imported Coal price	NT$/mt	BOFT
P_PETRO	Domestic petroleum price index	index	BOE
P_ELEC	Domestic electricity price	NT$/kWh	Taipower company
INCOME	National income	million NT$	DGBAS
POP	Population	person	Directorate General of Budget, Accounting and Statistics (DGBAS)

Note: Annual data is from 1991 to 2014. In the study, we use logarithmic transformed variables when estimating the price elasticity.

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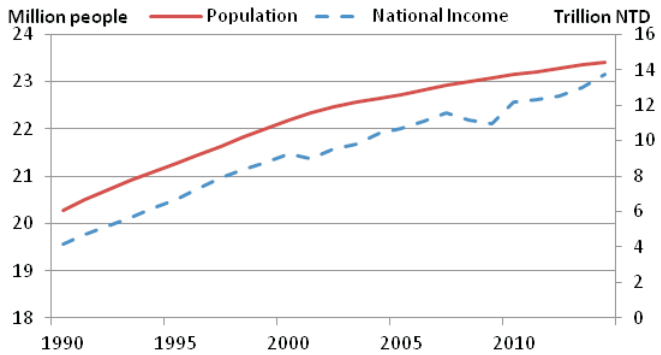


Figure A1: Population and national income of Taiwan

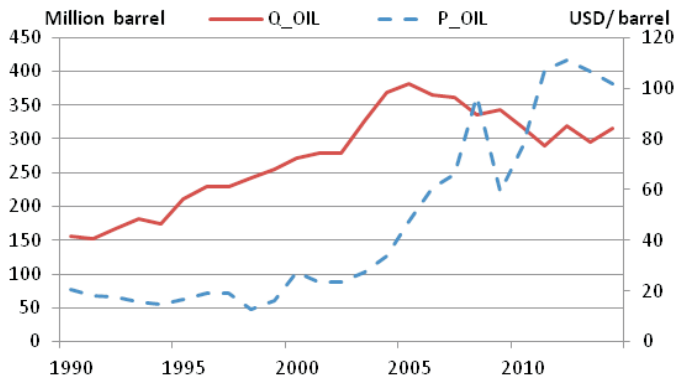


Figure A2: Import volume and import price of crude oil for Taiwan

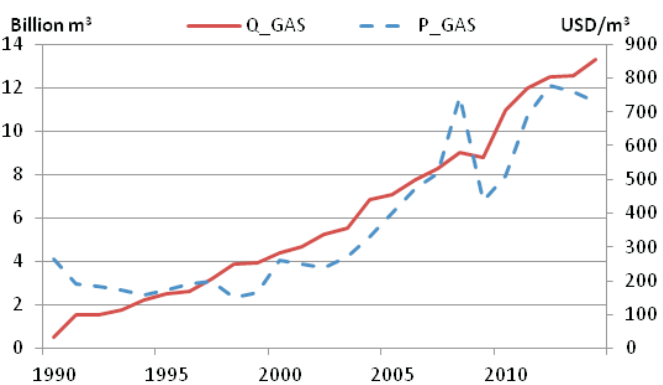


Figure A3: Import volume and import price of liquid natural gas for Taiwan

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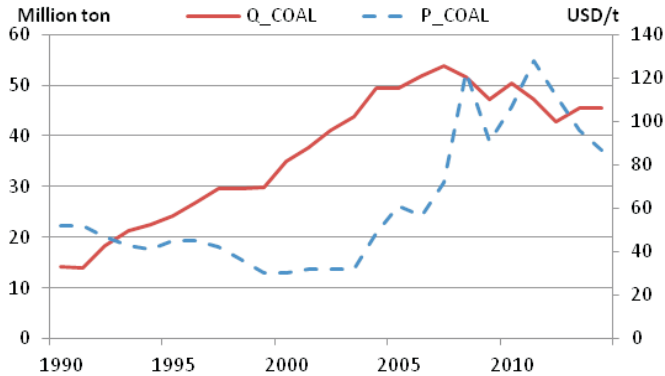


Figure A4: Import volume and import price of coal for Taiwan

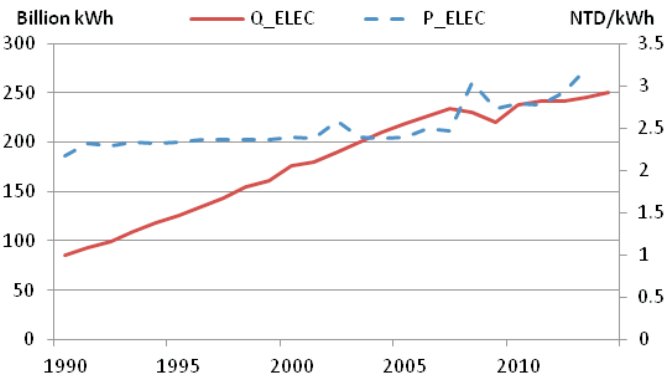


Figure A5: Consumption volume and price of electricity for Taiwan

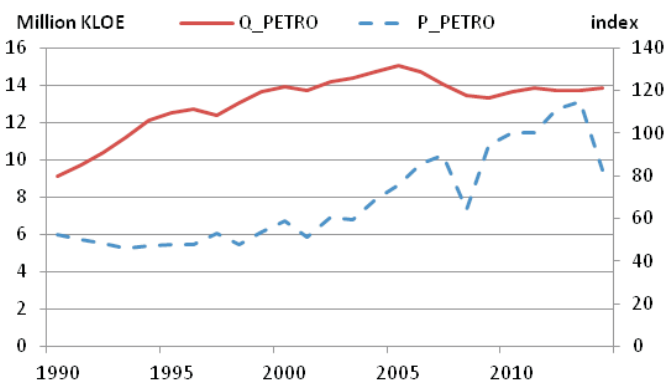


Figure A6: Consumption volume and price index of refined petroleum products for Taiwan

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Estimation Results for Price Elasticities

To estimate the price elasticities for energy products, we test the stationarity of the variables first and the results are shown in Table A4. As the table indicates, all variables (in logarithmic form) are integrated of degree one (except for POP using DF-GLS). Based on these results, we then conduct cointegration tests to examine whether there are cointegrating relationships existing among variables. The method we used is the typical Trace and Maximum Eigenvalue tests based on maximum likelihood estimation. Our results are shown in Table A5. According to the results, all energy products revealed to have at least one cointegrating vector, which allows us to examine the long-run price elasticity based on the estimated coefficients of the vector (Madlener, Bernstein, and Alva González, 2011). The elasticity estimates are shown in Table A6. It can be seen from Table A6 that two out of the five elasticities are insignificant (i.e. gas and electricity). However, all elasticities have correct sign and a magnitude which is less than 1, indicating that energy demands are inelastic with respect to price changes.

Table A4: Unit Root Test Results

	ADF test		DF-GLS test	
Variable	Level	differences	Level	differences
1 Q_OIL	−1.985(0)	−5.533**(0)	−0.983(0)	−5.190**(0)
Q_GAS	−2.491(5)	−16.919**(0)	0.438(4)	−5.879**(0)
Q_COAL	0.271(3)	−4.694**(1)	−1.213(3)	−5.598**(0)
Q_PETRO	0.724(1)	−2.371*(0)	−1.785(1)	−3.068*(0)
Q_ELEC	−0.988(0)	−5.674**(0)	−1.476(4)	−5.932**(0)
1 P_OIL	−0.207(0)	−4.458**(0)	−2.488(0)	−4.733**(1)
P_GAS	−0.307(0)	−4.614**(2)	−0.392(0)	−4.350**(0)
P_COAL	−0.451(0)	−4.316**(0)	−1.634(0)	−4.454**(0)
P_PETRO	−0.171(2)	−4.495*(1)	−1.102(0)	−5.347**(0)
P_ELEC	3.477(5)	−7.398**(0)	0.528(1)	−6.410**(0)
1 INCOME	−2.169(3)	−3.572**(0)	−1.809(0)	−4.609**(0)
POP	−2.154(4)	−3.185**(0)	−1.471(1)	−2.739(3)

Notes: 1. Annual data is from 1991 to 2014.
2. * denotes significant at the 5% level, ** denotes significant at the 1% level.
3. Lag lengths (in parentheses) are selected based on the Schwarz criterion (SC).
4. ELEC, OIL, COAL, GAS, PETRO, INCOME, POP denote Electricity, Crude oil, Coal, Natural gas, petroleum products, GDP, and population, respectively.

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Table A5: Cointegration Test Results

Energy product	Null hypothesis	λ_{Trace}	$\lambda_{MaximumEigenvalue}$
1 OIL	$r = 0$	29.49**	19.61*
	$r \leq 1$	9.88	9.75
	$r \leq 2$	0.14	0.13
GAS	$r = 0$	71.45**	35.37**
	$r \leq 1$	36.08*	18.56
	$r \leq 2$	17.52	13.38
COAL	$r = 0$	61.96**	27.97*
	$r \leq 1$	30.16**	22.00*
	$r \leq 2$	9.07	9.81
PETRO	$r = 0$	29.42*	21.42*
	$r \leq 1$	8.00	7.35
	$r \leq 2$	0.66	0.66
ELEC	$r = 0$	66.15**	37.81**
	$r \leq 1$	28.34*	18.66*
	$r \leq 2$	9.68	9.48

Notes: 1. 1. * denotes significant at the 5% level, ** denotes significant at the 1% level.

2. ELEC, OIL, COAL, GAS, PETRO denote Electricity, Crude oil, Coal, Natural gas, and petroleum products, respectively.

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Table A6: Estimated long-run relationships

Energy product	Cointegrating vector					
	Ln(Q_)	Ln(P_)	Ln(Income)	Ln(POP)	Ln(P_OIL)	C
OIL	1.000	0.649** (0.127)		−0.953** (0.037)		
GAS	1.000	0.393 (0.784)	−2.064** (0.193)		−0.577 (0.583)	17.796** (3.833)
COAL	1.000	0.620** (0.115)	−1.128** (0.016)		−0.442** (0.08)	
PETRO	1.000	0.388** (0.139)	−1.107** (0.037)			
ELEC	1.000	0.097 (0.857)	−1.088** (0.040)		−0.328** (0.094)	

Notes: 1. * denotes significant at the 5% level, ** denotes significant at the 1% level.

2. (·) indicates the standard errors.

3. ELEC, OIL, COAL, GAS, PETRO denote Electricity, Crude oil, Coal, Natural gas, and petroleum products, respectively.

4. The choice of whether to add a constant to the cointegrating vector for different energy products is mainly based on the Schwarz criterion (SC).

5. For OIL, we replace Ln(income) with Ln(POP) to obtain better estimates, as Ln(income) and Ln(POP) are closely related.

6. Similarly for GAS, PETRO, and ELEC, we add Ln(P_OIL) (the log of the price of oil) to take into account the substitutability among energy products and to obtain better estimates of price elasticities.

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Table A7: 1996 Hybrid Units Transactions Table at Producers' Prices

	1	2	3	4	5	6	7	8	9	10	11	12	Intermediate demand	Final demand	Total demand	Total domestic output	Import
Energy transactions in 10^9 kcal																	
1 Oil	0	0	0	323,592	0	0	0	0	0	0	0	0	323,592	5,544	329,136	538	328,598
2 Coal	0	6,034	0	0	130,774	0	10,651	22,480	0	3,459	0	0	173,399	46,053	219,452	15,687	203,765
3 Gas	0	0	0	6,743	13,760	0	970	3,655	516	256	0	1,405	27,306	10,822	38,128	7,208	30,920
4 Petroleum	0	79	3	16,665	60,332	9,303	18,179	12,131	1,253	20,167	1,692	123,209	263,010	55,813	318,823	274,681	44,142
5 Electricity	5	9	5	2,651	9,597	2,058	15,912	14,428	7,976	14,434	425	24,288	91,790	92,196	183,986	85,511	98,475
Value transactions in billions of NTD (in 2006 prices)																	
6 Agriculture, livestock, forestry, fishery, and other ores	0.00	0.8	0.0	1.6	0.0	107.2	11.6	55.8	0.7	298.3	33.3	1.9	504.9	251.1	756.0	580.1	175.8
7 Chemical and Chemical products	0.00	0.0	0.2	0.0	8.6	21.1	720.9	49.1	157.2	166.5	45.3	85.7	1,237.9	702.6	1,940.6	1,366.5	574.1
8 Metal and non-metal mineral products	0.00	0.1	0.1	0.0	0.1	2.4	21.1	817.1	379.6	41.3	297.1	19.0	1,557.0	856.6	2,413.6	1,794.7	618.9
9 Machinery and transport equipment	0.00	0.4	0.2	0.0	3.2	7.8	12.4	20.3	808.0	30.9	93.2	138.4	1,100.0	2,128.4	3,228.4	2,408.2	820.2
10 Other manufacturing products	0.00	0.1	0.4	0.0	0.9	96.7	48.0	19.2	34.0	519.7	48.5	181.9	936.8	1,519.5	2,456.3	1,881.3	575.0
11 Building construction	0.00	0.0	0.3	0.0	5.7	1.6	3.6	2.4	3.4	2.8	1.2	139.9	158.9	977.4	1,136.3	1,127.4	8.9
12 Services	0.02	3.2	9.3	0.0	30.4	59.4	190.7	350.3	345.9	236.8	235.4	1,367.4	2,791.4	5,091.2	7,882.7	7,328.2	554.5
Intermediate input	0.05	39.0	32.2	393.1	217.7	317.9	1,127.5	1,431.6	1,756.5	1,341.5	768.7	2,101.9	9,527.7	10,955.6	21,435.3	16,347.3	4,122.4
Value added	0.33	2.9	23.6	32.9	84.5	262.2	239.0	363.2	651.8	539.8	358.8	5,226.3	7,785.1	216.1	0.0	0.0	0.0

Notes: 1. Final demand includes private consumption, government consumption, fixed capital formation, inventory change, and export. 2. Due to the fact that government agencies usually revise their statistics after the year of publication, the numbers in the table might not exactly the same as those found in most recent published figures.

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Table A8: 2001 Hybrid Units Transactions Table at Producers' Prices

	1	2	3	4	5	6	7	8	9	10	11	12	Intermediate demand	Final demand	Total demand	Total domestic output	Import
Energy transactions in 10^9 kcal																	
1 Oil	0	0	0	397,673	0	0	0	0	0	0	0	0	397,673	1,469	399,142	366	398,777
2 Coal	0	14,998	0	0	234,379	0	21,717	20,928	0	2,513	0	0	294,534	44,679	339,213	21,561	317,652
3 Gas	0	0	0	4,529	41,276	0	703	3,713	2,356	424	0	1,848	54,850	7,828	62,677	6,793	55,884
4 Petroleum	0	97	0	21,236	55,811	8,318	17,576	10,351	4,795	20,037	1,487	137,643	277,351	67,490	344,841	327,129	17,711
5 Electricity	17	3	471	3,054	12,020	2,150	24,194	17,778	16,286	14,947	467	33,200	124,586	95,122	219,708	127,231	92,478
Value transactions in billions of NTD (in 2006 prices)																	
6 Agriculture, livestock, forestry, fishery, and other ores	0.00	2.5	0.0	1.5	0.0	100.1	14.9	73.5	0.4	243.0	51.0	1.8	488.9	243	732	541	191
7 Chemical and Chemical products	0.00	0.0	0.7	6.3	6.8	24.1	1,086.3	55.2	299.7	215.4	45.0	122.1	1,861.6	742	2,603	1,940	663
8 Metal and non-metal mineral products	0.00	0.1	0.4	1.5	0.3	4.0	33.0	1,112.3	539.6	66.8	330.2	24.1	2,112.2	550	2,663	2,060	603
9 Machinery and transport equipment	0.00	0.7	0.3	1.7	15.3	9.2	19.0	26.6	1,377.5	34.1	107.6	173.0	1,764.9	3,233	4,998	3,604	1,395
10 Other manufacturing products	0.00	0.1	0.6	0.5	1.0	77.6	35.4	15.0	39.7	502.1	29.0	207.4	908.4	1,524	2,433	1,838	595
11 Building construction	0.00	0.0	0.9	0.5	7.3	1.6	4.2	3.2	6.6	3.5	1.0	147.5	176.4	968	1,145	1,135	10
12 Services	0.02	3.2	4.6	24.3	19.6	57.1	205.4	289.9	516.4	241.4	184.1	2,055.1	3,601.0	6,605	10,206	9,551	655
Intermediate input	0.07	50.2	39.3	645.4	273.8	307.5	1,702.8	1,704.9	2,827.3	1,367.1	780.4	3,046.2	12,745.1	13,713	26,922	20,000	5,031
Value added	0.22	2.8	18.5	71.2	119.4	233.9	237.6	354.7	776.2	470.9	354.4	6,505.2	9,145.1	191	0	0	0

Note: Final demand includes private consumption, government consumption, fixed capital formation, inventory change, and export.

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Table A9: 2006 Hybrid Units Transactions Table at Producers' Prices

	1	2	3	4	5	6	7	8	9	10	11	12	Intermediate demand	Final demand	Total demand	Total domestic output	Import
Energy transactions in 10^9 kcal																	
1 Oil	0	0	0	522,438	0	0	0	0	0	0	0	0	522,438	−233	522,204	212	521,992
2 Coal	0	16,226	0	0	309,332	0	28,265	24,623	0	2,987	0	0	381,434	43,302	424,736	22,235	402,500
3 Gas	0	0	0	2,592	70,517	0	1,401	4,653	1,947	483	0	3,099	84,693	10,490	95,184	3,704	91,480
4 Petroleum	0	177	0	22,657	45,845	5,638	16,522	11,366	1,751	14,822	805	155,026	274,610	182,409	457,018	430,068	26,951
5 Electricity	72	1	670	3,032	13,909	2,554	30,296	22,380	28,178	14,828	464	41,661	158,044	110,313	268,358	164,455	103,903
Value transactions in billions of NTD (in 2006 prices)																	
6 Agriculture, livestock, forestry, fishery, and other ores	0.00	0.0	0.0	1.1	0.0	93.5	14.9	80.8	0.2	210.6	33.5	17.6	452.1	256	708	529	179
7 Chemical and Chemical products	0.00	0.1	0.3	6.5	3.9	21.2	1,404.5	71.2	401.2	196.8	42.9	189.7	2,338.3	1,043	3,381	2,394	987
8 Metal and non-metal mineral products	0.00	0.1	0.2	2.7	0.5	2.3	35.2	1,308.6	570.8	58.4	409.7	56.7	2,445.3	847	3,292	2,421	872
9 Machinery and transport equipment	0.01	1.4	0.5	3.3	13.0	8.8	14.4	25.7	2,555.7	72.2	134.3	230.5	3,059.8	5,531	8,591	5,865	2,725
10 Other manufacturing products	0.00	0.1	0.1	1.0	0.4	69.0	26.4	12.9	53.2	484.3	32.8	316.8	997.2	1,576	2,574	1,852	722
11 Building construction	0.00	0.1	0.6	4.0	1.1	1.7	10.0	9.9	10.6	4.3	1.2	151.2	194.6	1,064	1,259	1,259	0
12 Services	0.02	1.9	4.0	28.9	22.7	58.1	212.1	325.0	843.6	316.2	240.6	2,701.2	4,754.3	8,647	13,402	12,591	811
Intermediate input	0.19	32.4	44.8	908.7	337.1	295.4	2,057.9	1,968.5	4,520.4	1,405.8	912.6	4,094.5	16,578.4	19,553	36,132	28,555	7,577
Value added	0.11	6.6	14.3	128.3	171.5	233.8	336.3	452.1	1,344.8	446.2	346.0	8,496.3	11,976.5	267	0	0	0

Note: Final demand includes private consumption, government consumption, fixed capital formation, inventory change, and export.

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台灣出口品之能源及碳隱含量: 投入產出結構分解分析

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本文估算台灣 1996、2001 及 2006 年出口品的能源及碳隱含量, 以衡量能源及碳隱含量的變化情形及其影響因素。文中利用結構分解分析將出口品能源及碳隱含量變化的影響因子區分爲五個因子, 結果發現在 1996 至 2001 年間, 能源使用效率、中間財的投入結構, 以及出口結構的變化是造成台灣出口品能源及碳隱含量變化的主要因素; 而在 2001 至 2006 年間則是以出口結構的變化爲主要影響因子。此外, 本文也同時評估台灣能源政策對減少出口品之能源及碳隱含量的有效性, 研究結果顯示, 在 1996 年至 2001 年間, 若對化石能源課徵碳稅僅能微幅降低出口品之能源及碳隱含量, 但在 2001 年至 2006 年間卻能使出口品之能源及碳隱含量明顯的減少, 亦即在 2001 年至 2006 年間碳稅政策較前一段期間來得更有效。

關鍵詞: 碳隱含量, 投入產出, 結構分解分析, 能源稅
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