Analysis of the regional impacts of Climate Policy in Japan

Shigeharu Okajima

Department of Agricultural, Environmental and Development Economics

The Ohio State University

Okajima.3@osu.edu

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Abstract

After great improvements in energy efficiency in the 1970's, Japan has made little progress in reducing energy consumption since 1990, the base year for the Kyoto Protocol. This study is motivated by the recent growing demands among policy makers to find all possibilities for saving energy. To make informed decisions on how to save energy, policy makers need detailed information on energy consumption structures within each jurisdiction.

First, in this article, I decompose national level energy intensity into efficiency and activity effects with the Fisher Ideal index, and then estimate regressions on prefecture level residential electricity demand between 1990 and 2003. It is found that national level energy intensity declined by seventy three percent from 1970 to 2003; sixty three percent of the decline may be attributed to improvement in energy efficiency. Energy intensity, however, has slightly increased since early 1990's.

Secondly, this paper explores the impact of reduction of carbon emission on the economy. I find that the Japanese government needs to enact the environmental taxes on a $12/ton in order to meet the Kyoto Protocol. It is also found that imposing a $12/ton environmental tax reduces Japanese GDP by around six percent and equivalent variations in urban regions fall while equivalent variations in rural regions rise.

Keywords: Fisher index; Energy intensity; Regional Computable General Equilibrium; Environmental taxes

Ⅰ. INTRODUCTION

After the Kyoto Protocol, many countries agreed to reduce carbon emissions to slow global warming. Japan, for example, has to reduce carbon emissions by six percent compared to 1990 emissions levels and the government started trying to find ways to meet the obligation. It seems, however, that there are many different factors that influence the carbon emitted in each region and that the central government does not always recognize them. For instance, Hokkaido, the northernmost prefecture in Japan, has a lot of snow. As a result, people living there may use more electricity during winter than those who are in warmer regions. Another example is population density. If population density has a positive effect on decreasing energy consumption, the energy consumption per capita in Tokyo, which is the most populated prefecture in Japan, may be smaller than that of a less densely populated area. Also, some prefectures have a lot of heavy industries so they may consume more energy than those with fewer such industries. When energy consumption structures differ between regions, energy saving measures need to vary by region based on the differences. Thus, the central government either needs to fully understand regional differences in energy consumption patterns in order to make informed decisions on how to save energy, or it should allow each local government to take leadership in reducing energy consumption within its area of jurisdiction. This paper investigates the impacts of the regional level policies to limit Japanese carbon dioxide emissions.

Okajima (2008) decomposes energy intensity into efficiency and activity effects using the Fisher Ideal index in order to determine which prefectures have been most effective in improving their energy efficiency since 1990 in Japan. When energy intensity declines, there are two possible reasons for the decline. First, energy efficient technologies or energy saving measures are adopted and thus less energy is used to produce the same amount of GDP. Second, structural

changes happen and the number of energy intensive industries decreases, while the number of less energy intensive industries, such as the service industry, grows. These changes, i.e. improvements in energy efficiency and structural changes, are essentially different. The former is called energy efficiency and the latter is called economic activity. By distinguishing energy efficiency from economic activity, we can tell how much of the decline in energy intensity is due to the pure efforts to save energy.

In this paper, we discuss two policy issues. First, I examine how regional welfare will change if the Japanese government imposes environmental taxes to reduce Japan's aggregated carbon emissions. From Okajima (2008), it is found that some prefectures have been more effective in improving their energy efficiency compared to other prefectures. Also, each prefecture has different geographic features and climate conditions which affect energy consumption. The study implies that each region has different preference for energy consumption. Thus, I use different utility functions for each region to analyze the impact of environmental taxes at the regional level. There is a stream of policy literature that studies regional taxes. One complication of changing tax rates among regions is the "leakage" effect, which is also known as "pollution haven" effect. When tax rates are different among regions, inter-regional firms can reduce production in regions with higher taxes, and instead, increase activities in the other regions to compensate the decrease. Therefore, this paper assumes that policy makers impose the same tax rate on all regions and investigates equivalent variation of each region in order to estimate the effectiveness of environmental taxes more accurately.

Another policy issue studied in this paper is the "rebound" effect. In general, rebound effect means that a policy exhibits such effects that are totally opposite to policy makers' original intention. For example, poorly planned environmental policies could induce more energy

consumption. Many studies emphasize that emission taxes generate revenues that can be used for finance cut in existing distorted taxes, which in turn avoids some of the deadweight costs associated with distorted taxes. However, these policies may encourage people to consume more goods than before. In this paper, we assume that the production taxes are distorted. The central government will evenly redistribute revenue from the production taxes to each region. The reduction of finances by the production tax cut is then covered by the environmental tax. We estimate how the policy affects the level of carbon emissions.

A CGE model is proposed to analyze environmental taxes and the rebound effect. According to Partridge and Rickman (1998), CGE models are a powerful tool to analyze inter-regional climate policies. CGE models allow us to simulate the effects of economic policies and to analyze the aggregate welfare and distributional impacts of policies. For example, Li and Rose (1995) examine the effect of an emission limit on a single state, modeled as a small open economy. Balistreri and Rutherford (2004) and Ross et al. (2004) perfom similar analysis using models which resolve one state but aggregates the remainder of the economy into five census regions. Sue Wing (2007) is the first to simultaneously resolve all U.S. states, and to simulate both the interstate system of taxes and transfers as well as general equilibrium effects of abatement on the distribution of income.

This paper is unique in that it constructs a computable general equilibrium model which divides the Japanese economy into eight industries and eight regions, and simulates the effects of environmental policies in order to investigate the potential impact on Japanese economy. Although the details of regional differences are important for both local and the central government decision making, there has been no study investigating energy consumption or demand structure within Japanese prefectures. A major reason for a lack of regional studies is

that little reliable data on regional energy consumption has been available in Japan. Scarce as it still is, prefecture level data is becoming more readily available. We use the data on energy consumption in Japanese prefectures in the period of 1990 to 2003 which was released by the Research Institute of Economy, Trade and Industry in 2006.

The remaining sections of the paper are organized as follows: the second section presents Japan's energy consumption trend; the third section describes the decomposition and analyses of energy intensity at the national and prefecture level using a decomposition method; the forth section presents the structure of the CGE model and the simulation results; and the fifth section provides concluding remarks.

Ⅱ. JAPANESE ENERGY CONSUMPTION TREND

As a first step, I examine Japan's energy consumption trend in the last few decades. The reason why energy consumption trend is analyzed, instead of carbon emissions, is that there is not enough data about carbon emissions in the past 40 years at regional levels. However, energy consumption correlates closely to carbon emissions. Therefore, it is reasonable to examine the trend of Japanese energy consumption, instead of Japanese carbon emissions. Overall, Japan has become very energy efficient since the 1970's, but progress is not uniform between sectors. Industry reduced energy consumption dramatically, while the transportation, commercial, and residential sector increased energy consumption continuously. In this section, I first outline Japan's energy consumption trend. Then I present the energy issues that the Japanese government now confronts.

A. Japan's Energy Consumption Trend

Figure 1 shows energy consumption in Japan from 1965 through 2004. Energy consumption increased by an average of 3.4% a year over the period. The rate of increase was as high as 11.8% prior to 1974, concurrent with Japan's rapid economic growth from 1966 to 1973. Hit by two oil crises, energy consumption did not grow very much from 1974 to 1982. In 1983, energy consumption returned to the pre oil crises levels and increased during Japan's bubble economy from 1986 to 1991. The average increase rate between 1987 and 1990 was 4.0%. Although energy consumption slowed down when economic stagnation began in 1991, it kept increasing by 1.0% per year thereafter.

(Figure 1 here)

Figure 2 shows energy consumption by energy consuming sectors. Japanese industry became remarkably energy efficient in the face of the oil crises. Japan's oil dependence was 77% before the 1973 oil crisis and 99% of the oil was imported. Thus, the strong anxiety for oil supply spurred Japanese industry to energy saving efforts. Industrial energy consumption increased by 253% from 1965 to 2004, while transportation, commercial and residential energy consumption increased by 483%, 857% and 467% respectively.

(Figure 2 here)

Energy consumption per GDP dropped 76% from 1965 to 2004 (see **Figure 3**). It was already decreasing prior to 1974 and the oil crises accelerated the trend further. This is due to efforts by industry, as stated above. Although energy consumption per GDP still continued to

decline at a slower pace during the bubble economy, it slightly increased when Japan entered economic stagnation and both energy consumption per capita and GDP per capita leveled off.

(Figure 3 here)

B. Japan's Energy Issues

After the great improvements made in the 1970's, Japanese energy saving efforts seem to have reached a ceiling. Energy consumption per GDP has been gently increasing since 1990 but had been declining before the 1980's. Even though the pace has slowed down since 1990, energy consumption has been rising as well. Japan has to reduce greenhouse gas emissions by six percent below the 1990 level by 2008 to 2012 to meet the obligations of the Kyoto Protocol. This is a great challenge as Japan's energy efficiency improved greatly before 1990 and has been deteriorating ever since. In reality, energy consumption grew by 115% from 1990 to 2004.

Observing the energy consumption trends, I have found that Japanese industry has become very energy efficient. Taking into account the fact that manufacturing companies have relocated their plants overseas since the early 1990's with only their offices remaining in Japan, as well as their tireless efforts in past decades, there is little room for improvement in the industrial sector.

On the other hand, energy consumption in the transportation, commercial and residential sector has been growing rapidly. In 1965 energy consumption in these three sectors represented 36 % of aggregate energy consumption. However, the percentage went up to 55% in 2004. Therefore, it is especially important to improve energy use in the transportation, commercial, and residential sector in order to reduce Japan's aggregate energy consumption. With these issues in mind, I examine the factors which affect energy intensity in the next section.

Ⅲ. DECOMPOSITION OF ENERGY INTENSITY

In this section, I analyze energy intensity trends. Energy intensity is the ratio of energy use to activity, and is usually obtained by dividing GDP into energy consumption. Unlike energy consumption per capita, energy intensity can tell how efficiently energy is used and can be used to compare different levels of energy use. As energy consumption is essential to economic activities, simply capping energy use may deteriorate the economy. Instead, energy intensity should be used to evaluate energy saving efforts. In the following section, I decompose an energy intensity index into an efficiency and activity index. First, I explain the decomposition method with the Fisher Ideal index. Then, I apply the method to national and prefecture level energy consumption in Japan. Again, the reason why energy consumption trend is analyzed, instead of carbon emissions, is that there is not enough date about carbon emissions in the past 40 years at regional levels. However, energy consumption correlates closely to carbon emissions. Therefore, it is reasonable to examine the trend of Japanese energy consumption, instead of Japanese carbon emissions.

A. Decomposition Method of Energy Intensity

When energy intensity declines, there are two possible reasons for the decline. First, energy efficient technologies or energy saving measures are adopted and thus less energy is used to produce the same amount of GDP. Second, structural changes happen and the number of energy intensive industries decreases, while the number of less energy intensive industries, such as the service industry, grows. These changes, i.e. improvements in energy efficiency and structural changes, are essentially different. The former is called energy efficiency and the latter

is called economic activity. By distinguishing energy efficiency from economic activity, we can tell how much of the decline in energy intensity is due to the pure efforts to save energy.

Over the past few decades, a considerable number of studies have been conducted on index numbers that are used to decompose aggregate energy intensity into component elements of energy efficiency and economic activity. Boyd et al. (1987) introduced the Divisia index approach and Tornqvist approximation. These decompositions, however, had a residual term. If there are residual terms, they may have effects on an energy intensity index and we may misinterpret results. Therefore, we have to think about another index approach that has no residual term. Fisher (1921) indicated that Fisher Ideal indices can completely decompose an expenditure index into a price and quantity index. Applying this idea, Boyd and Roop (2004) showed that the Fisher ideal index provides a perfect decomposition of an aggregate energy intensity index into an economic activity and an energy efficiency index with no residual. However we cannot always accomplish this decomposition. According to Diewert (2001), we can achieve this decomposition if the following conditions are met: we can construct sectors that account for all energy use in the economy without overlap; and, there exists a set of economic activity measures Y_{it} with which to construct a measure of energy intensity.

Aggregate energy intensity (e_t) is a function of sectoral energy efficiency (e_{it}) and sectoral activity (a_{it}).

$$e_t \equiv \frac{E_t}{Y_t} = \sum_i \left(\frac{E_{it}}{Y_{it}} \right) \left(\frac{Y_{it}}{Y_t} \right) \equiv \sum e_{it} a_{it} \qquad (1)$$

where E_t is aggregate energy consumption in year *t*, E_{it} is energy consumption in sector *i* in year *t*, Y_t is GDP in year *t*, and Y_{it} is a measure of economic activity in sector *i* in year *t*. The

sum total of energy consumption in sectors must be equal to aggregate energy consumption, whereas the sum total of measures of economic activity needs not equal to GDP.

I first construct the Laspeyres and Paasche index and an efficiency and activity index in order to construct the Fisher Ideal index. In terms of energy intensity, the Laspeyres approach uses a base year fixed weight for energy consumption and economic activity measures. The Laspeyres index is

$$L_t^{act} = \frac{\sum_i e_{i0} a_{it}}{\sum_i e_{i0} a_{i0}} \tag{2}$$

$$L_t^{eff} = \frac{\sum_i e_{it} a_{i0}}{\sum_i e_{i0} a_{i0}} \tag{3}$$

where L_t^{act} is the Laspeyres activity index and L_t^{eff} is the Laspeyres efficiency index. By reversing the role of the base year (t=0) and the end year (t=T), we can construct the Paasche index. Therefore the Paasche index is

$$P_t^{act} = \frac{\sum_i e_{it} a_{it}}{\sum_i e_{it} a_{i0}} \tag{4}$$

$$P_t^{eff} = \frac{\sum_i e_{it} a_{it}}{\sum_i e_{i0} a_{it}} \tag{5}$$

where P_t^{act} is the Paasche activity index and P_t^{eff} is the Paasche efficiency index. The Fisher Ideal index is the geometric average of the Laspeyres and Paasche index. The Fisher Ideal index is

$$F_t^{act} = \sqrt{L_t^{act} P_t^{act}} \tag{6}$$

$$F_t^{eff} = \sqrt{L_t^{eff} P_t^{eff}} \tag{7}$$

According to Boyd and Roop (2004), the Fisher Ideal index satisfies the property equivalent to perfect decomposition. The property, *factor reversal*, means that an acceptable functional form of the price index $p(p_{0,} p_{T,} q_{0,} q_T)$ should be acceptable to the quantity index $Q(p_{0,} p_{T,} q_{0,} q_T)$ as well with the roles of the price and quantity vector reversed and that the quantity index must satisfy $\frac{V_T}{V_0} = P(q_{0,} q_{T,} p_{0,} p_T)\, Q(p_{0,} p_{T,} q_{0,} q_T)$. Thus, the Fisher Ideal index allows us to segment an aggregate energy intensity index into an efficiency and activity index with no residual. Denoting e_0 as aggregate energy intensity for a base year, an energy intensity index (I_t) can be constructed. The decomposition of an energy intensity index into an activity and efficiency index is

$$\frac{e_t}{e_0} \equiv I_t = F_t^{act} F_t^{eff} \tag{8}$$

Applying this decomposition method, we can determine how energy intensity would have changed if either an efficiency or activity index had not changed at all.

B. Energy Intensity Analysis at the National Level

In this section, I analyze the Fisher decomposition of national level energy intensity in Japan from 1970 to 2004 taking 1970 as a base year. I divide aggregate energy consumption into the industrial, transportation, commercial, and residential sector. The industrial sector is the manufacturing industry. Transportation includes passenger traffic and freight transport. The commercial sector includes companies' management departments, offices and buildings, and the service industry. The residential sector is all the household energy consumption except transportation. As economic activity measures, I use gross domestic product classified by economic activities for the industrial, transportation, and commercial sector, and national disposable income for the residential sector. The results are shown in **Figure 4**.

(Figure 4 here)

Energy intensity declined dramatically due mainly to improvements in efficiency. The efficiency index was 0.37 in 2004. This means that energy intensity would have been thirty seven percent of the 1970 level had it not been for structural changes. On the other hand, the activity index was 0.74 in 2004. This means energy intensity would have been seventy four percent of the 1970 level if efficiency had not changed at all. To put it another way, out of the seventy three percent decline in energy intensity, the sixty three percent is attributed to energy saving efforts, while the twenty six percent is attributed to structural changes.

The point to observe is that the efficiency and activity trends changed in the early 1990's. The improvement in efficiency maxed out in 1992, whereas structural changes speeded up after 1992. Thus, energy intensity rose after dropping to a minimum of 0.25 in 1992.

C. Energy Intensity Analysis at the Prefecture Level

Before I turn to the decomposition of prefecture level energy intensity, it is useful to be aware how energy intensity varies between prefectures. One sees from **Figure 5** that aggregate energy intensity in Tokyo is by far the lowest. In prefectures such as Yamaguchi, Oita and Okayama, aggregate energy intensity is quite high and so is the industrial energy intensity. These prefectures are all located in Japanese major industrial areas and have many energy intensive industries, i.e., iron and steel, chemicals, non metallic mineral products, pulp, paper and paper products industries. Energy intensity in the commercial sector does not vary greatly between prefectures, though some prefectures are clearly less efficient than the others. In the residential sector, the trends of energy intensity are quite similar between prefectures. Since Hokkaido, Aomori and Akita, the northernmost prefectures and Okinawa, the southernmost prefecture, have the highest energy intensity; there is a fair possibility of the existence of geographical factors.

(Figure 5 here)

For the Fisher decomposition of prefecture level energy intensity in Japan, I use a data set covering the period from 1990 to 2003 and take 1990 as a base year. I divide aggregate energy consumption into industrial, commercial, and residential sector. I do not include transportation as a sector. Data on energy consumption in the transportation industry are not gathered at the prefecture level, because operations of transportation companies range over many prefectures and thus their energy consumption cannot be allocated between prefectures. Energy consumption of household owned cars is included in the residential sector. As economic activity measures, I use gross prefectural domestic product classified by economic activities for the industrial and commercial sector, and prefectural income for the residential sector. The results

appear in **Figure 6.** It is found that the trends of energy intensity vary between prefectures because energy efficiency has worsened more in some prefectures than in the others. It is possible that some energy saving measures have been taken in the prefectures where energy efficiency has improved; on the other hand, there is little difference in structural changes between prefectures.

(Figure 6 here)

D. Energy Intensity Analysis at the Sectional Level

From the previous section, the initial reductions in energy consumption can be attributed mainly to improvements in efficiency. After 1990, the changing of economic activity had influenced on reduction in energy consumption; on the other hand, the reduction of aggregate energy intensity in Japan has stopped since 1990. The question we have to ask here is which sector did not improve energy-efficiency. Importantly, this question offers the key to an understanding of reducing energy consumption in the future. We can see how the energy efficiency has changed in each sector since 1990 in **Figure 7**. As **Figure 7** indicates, each sector has progressively become less energy efficient since 1990. Therefore, policy makers should take a decision that the each sector carries their share of burden.

(Figure 7 here)

Ⅳ. THE MODEL

From what has been discussed in previous chapters, we may conclude that energy intensity has slightly increased since early 1990's. It is also found that all sectors have not increased their efforts toward energy saving. Now, the Japanese government has begun to discuss proposals of

environmental taxes in order to reduce carbon emissions. However, the Japanese government has not figured out the effect of environmental taxes on the economy. Therefore, for policy makers to adopt appropriate polices, we need to analyze the effect of environmental taxes on the Japanese economy on regional and national basis.

This chapter presents the economic impacts of policy to mitigate the emission of heat-trapping greenhouse gases which are carbon dioxide, methane, nitrous oxide and fluorinated gases. Heat-trapping greenhouse gases contribute to global warming and the most important heat-trapping greenhouse gas is carbon dioxide.

Carbon dioxide emissions come primarily from the combustion of fossil fuels in energy use. For instance, on the supply side of the economy, fossil fuels are the large-scale source of energy, while, on the demand side of the economy, energy is employed as an input to every activity. Therefore, when policy makers adopt appropriate environmental policies to reduce carbon dioxide, these policies may cause large increases in energy prices, reduction in energy use, and declines in economic impacts and welfare.

There are two main polices to achieve emission reduction. One is price instrument which indicates environmental tax. Second is quantity instrument which indicates an emission cap and trading system. However, there are some critiques of quantity instrument. Firstly, cap and trade systems cannot reduce the sum total of carbon emissions in the world. For example, many developed countries may purchase "hot air" which is surplus credits to pollute held by former communist countries or developing countries. As a result, there is possibility of increasing the amount of carbon emission which everyone believes must decrease when cap and trade system is introduced. Secondly, the government may impose an additional burden on people to finance the

cost of hot air. This additional burden is no different from environmental taxes. For example, Japan's emissions climbed around 13 percent in 2005 versus the 1990 level in the latest government data, leaving it 19 percent off the Kyoto target to cut emissions. Analysts say it will struggle to meet the target without buying hot air from former communist countries. However, the Japanese government has no idea how to finance the cost of hot air.

Therefore, this paper only adopts price instrument in order to investigate how much effect the environmental tax has on the economy.

A. Model structure

I present the structure of the model used for a static price equilibrium simulation of Japanese economy. This model is refereed to Sue Wing (2004).

Firms are classified into 8 aggregate sectors: coal mining, natural gas distribution, refined petroleum, electric power, energy-intensive manufacturing (an amalgam of the chemical, ferrous and non-ferrous metal, pulp and paper, and stone, clay and glass industries), transportation, service and the remaining manufacture. Labor and capital are the primary factors. Each firms produce output from capital, labor and intermediate inputs (energy goods and non energy goods), according to nested CES production functions which is referred to Bosetti et al. (2006). To put it more concretely, the output of the j-th industry, y_j, is combining N types of intermediate goods imput, x, E types of fossil fuel commodities, e, capital input, K, and labor input, L, according to the nested CES production function:

$$y_j = \left(\beta_j^{klem} \, y_j^{kle} \, {}^{(\sigma_j^{klem}-1)}\!/_{\sigma_j^{klem}} + \sum_{i=1}^{N} \gamma_{i,j}^{klem} \, x_{i,j} \, {}^{(\sigma_j^{klem}-1)}\!/_{\sigma_j^{klem}} \right)^{\sigma_j^{klem}/(\sigma_j^{klem}-1)} \tag{9}$$

$$y_j^{kle} = \left(\beta_j^{kle} \, y_j^{kl} \, {}^{(\sigma_j^{kle}-1)}\!/_{\sigma_j^{kle}} + \sum_{e=1}^{E} \gamma_{e,j}^{kle} \, e_{e,j} \, {}^{(\sigma_j^{kle}-1)}\!/_{\sigma_j^{kle}} \right)^{\sigma_j^{kle}/(\sigma_j^{kle}-1)} \tag{10}$$

$$y_j^{kl} = \left(\beta_j^{kl} \, K_j \, {}^{(\sigma_j^{kl}-1)}\!/_{\sigma_j^{kl}} + \gamma_j^{kl} \, L_j \, {}^{(\sigma_j^{kl}-1)}\!/_{\sigma_j^{kl}} \right)^{\sigma_j^{kl}/(\sigma_j^{kl}-1)} \tag{11}$$

where $\beta_{i,j}$ and $\gamma_{f,j}$ are the technical coefficients, while σ_j denotes each industry's elasticity of substitution. Moreover y_j^{kl} is composite goods of capital and labor, and y_j^{kle} is composite goods of capital-labor and energy goods.

Households differ in their preferences. For example, Hokkaido, the northernmost prefecture in Japan, has lots of snow. As a result, people living there may use more electricity during winter than those who are in warmer regions. Thus, preference of people living in Hokkaido is different from preference of people living in other regions. This paper divides Japan into 8 regions in order to take several households with different preference into consideration.

There are three types of household demand for commodities of final uses: consumption, investment, and net exports. Investment and net exports are assumed to be exogenous and constant. Households in each region are modeled as a utility-maximizing representative agent with CES preferences over their consumption of commodities. Consumption is financed out of the income which each regional agent receives from the rental of their endowments of labor and capital to industries. To put it more concretely, the j-th household utility, U_j , is related to the consumption, c, of the N commodities by the CES function:

$$U_j = \left(\sum_{i=1}^{N} \alpha_{i,j} C_j^{(\omega-1)/\omega} \right)^{\omega/(\omega-1)} \quad (12)$$

where $\alpha_{i,j}$'s are the technical coefficients of the utility function, and ω is the elasticity of substitution.

An important feature is that this model uses revenues accruing from environmental taxes in order to reduce pre-existing distortions brought by pre-existing distorting taxes. Several studies have been made on the possibility of substituting environmental taxes for pre-existing distorting taxes in order to lower the efficiency cost. This approach is referred to as "revenue recycling." This paper assumes that pre-existing ad-valorem taxes on production and imports bring about pre-existing distortions. Under these situations, imposing environmental taxes may leave the economy worse. Now, policy makers need to maximize gains in economic efficiency. So I assume that the revenue, raised by pre-existing ad-valorem taxes on production and imports, is recycled to the representative agent in a lump sum.

B. Data

For the benchmark dataset, I use Japanese input-output tables for the year 2000 provided by Japanese Ministry of Internal Affairs and Communications. The data of CO2 emissions in the year 2000 from coal, petroleum and natural gas are obtained by Greenhouse Gas Inventory Office in Japan. Following Sue Wing (2004), this paper assumes that both σ_j's, each industry's elasticity of substitutions, and ω, elasticity of substitution, are 1.

C. Environmental taxes

The model attempts to simulate the effect of imposing environmental taxes on emission of CO2. To calculate the burden of environmental taxes on industries and the representative agent, it is necessary to examine the relationship between the levels of production and demand activities and the quantity of emissions. This is because it is difficult to correctly grasp how much CO2 each sector emits. Therefore, instead of directly imposing environmental taxes on the activity emitting CO2, it is better to impose environmental taxes on fossil fuel commodities when these commodities are traded in the market. The simplest way of doing this is to assume a fixed relationship between the aggregate demands for fossil fuel commodities in which carbon is embodied, such as coal, refined petroleum and natural gas. Therefore, a tax on carbon results in a set of commodity taxes that are differentiated by energy goods' carbon contents, and acts to increase the gross-of- advalorem-tax price of each fossil fuel.

The model is simulated to reproduce the benchmark as a baseline no-policy case. Next, I constructed a series of counterfactual shocks by levying carbon taxes that range between \$3/ton and \$12/ton CO2, in order to attain the Kyoto protocol. According to Sue Wing (2004), "a

potential source of confusion in that GHG taxes are usually specified in units of carbon while environmental statistics usually account for GHG emissions in units of CO2. The ratio of these substances' molecular weights (0.273 tons of carbon per ton of CO2) establishes an equivalency between the two measures." Therefore, the values of a tax on carbon become equivalent to taxes on CO2: $0.819, $1.638, $2.457 and $3.276 per ton of CO2 respectively.

D. Result

In this section, I present results from the numerical analysis. In order to attain the Kyoto Protocol, Japan has to reduce carbon emissions by six percent compared to 1990 emissions level. CO2 emissions in the year 1990 were 1,144 MT. Therefore, Japan has to reduce CO2 emissions to 1,079 MT.

The model simulates the effects of imposing range of additional taxes on emissions of CO2. Table 1 shows the impact of CO2 reduction on GDP. In order to reduce CO2 emissions to 1,079 MT, the Japanese government needs to impose a $12/ton tax. A 7 percent fails in GDP.

This model assumes that ad-valorem taxes on production are levied on the output of each industry. Also, these taxes discourage economically desirable activities. Now, this paper assumes that the central government collects tax revenue and allocates it to each household evenly as a lump-sum supplement to the income, because the central government's imposing environmental taxes cause to raise the tax burden ratio.

(Table 1 here)

To capture aggregate impact of policies, I use Equivalent variations because this indicator is one of the well micro-founded indicators. This result appears in Table2.

Equivalent variations of Hokkaido region, Tohoku region and Shikoku region are positive. This means that revenue from pre-existing production taxes offsets the cost of environmental taxes. On the other hand, equivalent variations of other regions are negative. This means that revenue from pre-existing production taxes could not offset the cost of environmental taxes.

Let us look at this result from a different angle. Equivalent variations of Kanto region and Kinki region decrease to more than 10 percent. A plausible explanation of this is Kanto region and Kinki region are urban regions. Therefore people who live there are more dependent on energy commodities than those who live in rural regions. In other words, Hokkaido region, Tohoku region and Shikoku region are rural regions. Therefore people who live there may not be dependent on energy commodities than people who live in urban regions.

(Table 2 here)

Table 3 shows how much carbon tax raises the consumer price. Increase in consumer price of coal is higher than increases in consumer price in any other sectors. A $3/ton carbon tax raises the consumer price of coal by 3 percent, and a $12/ton carbon tax raises the consumer price of coal by 11 percent. This is because coal is the most carbon-intensive energy source compared with other energy sources, such as oil and gas.

(Table 3 here)

Table 4 indicates changes in final consumption by commodities. Table 5 shows changes in sectoral activity level. The changes in final consumption of commodities and in sectoral activity levels correspond closely to changes in gross-of-tax commodity prices (Table 3).

(Table 4 and Table 5 here)

Also the impacts of environmental policy interventions on pollution are investigated by CGE model. Figure 8 shows emissions from each sector. In order to reduce carbon emission by six percent compared with 1990 emissions levels, the Japanese CO2 target is 1,079 MT. As mentioned above, in order to reduce CO2 emissions to 1,079 MT, the Japanese government needs to impose a $12/ton tax. The coal sector and the oil sector reduce the carbon emission by around 30 percent, while other sectors reduce the carbon emission by less than 10 percent.

(Figure 8 here)

E. Sensitivity Analysis

To test the generality of the result above, I have run a series of sensitivity analysis. In order to test the accuracy of this model, we need two criterions. First criteria is that when the elasticity of substitution is changed, the direction of change in each production is unchanged. Second criteria is that when the elasticity of substitution is changed, the order of change in each production is still the same.

Although the model assumes that the elasticity of substitution for the CES production function between input commodities and energy commodities is 1, in order to investigate robustness, I conducted experiments with the elasticity of substitution for the CES production function between input commodities and energy commodities is 0.8 and 1.2, respectively. This analysis results in Table 6. Table 6 clearly shows that the results of simulations are reliable because both of criterions are satisfied.

(Table 6 here)

V. CONCLUSION

In conclusion, I would like to state the following two points. Firstly, I applied the energy intensity decomposition method with the Fisher Ideal index to Japanese energy intensity. It is found that at the national level, energy intensity declined by seventy three percent from 1970 to 2003. Furthermore, the sixty three percent of the decline is attributed to improvement in energy efficiency. Energy intensity, however, has slightly increased since early 1990's. The results show that at the prefecture level, improvements in energy intensity have not been uniform after 1990. It is also found that each sector has to put more effort in order to reduce carbon emissions by six percent compared to 1990 emissions level.

Secondly, this paper explores the potential impact reduction of carbon emission on the economy. I find that the Japanese government needs to enact the environmental taxes on a $12/ton in order to meet the Kyoto Protocol. It is also found that imposing a $12/ton environmental tax reduces Japanese GDP by around six percent and equivalent variations in urban regions fall while equivalent variations in rural regions rise.

Finally, I point out several future research directions. First, the model is static which means that static models cannot deal with issues of next periods. This model assumes that investment demand of each commodity is fixed. However, a more realistic model, like dynamic models, would let households adjust saving and investment behavior to a tax shock, due to the forward-looking behavior of households. Therefore, this simple static general equilibrium model needs to be transformed into a dynamic model.

Second, the economy's net export position is assumed to be constant. I need to extend this model into a small open economy model in order to model the economy's net export position as an endogenous variable. One way to extend this model is that we let imports and exports linked by the balance-of-payment condition and assume that imports and domestically supplied goods are aggregated to be Armington's (1969) composite goods.

Lastly, we have to consider how the central government allocates revenue from pre-existing production taxes to each region. This paper evenly distributes revenue from pre-existing production taxes to each region. However, each region has a different economics situation. For example, some regions pay more production taxes than other regions. Therefore policy makers have to consider how they can fairly distribute revenue from pre-existing production taxes to each region.

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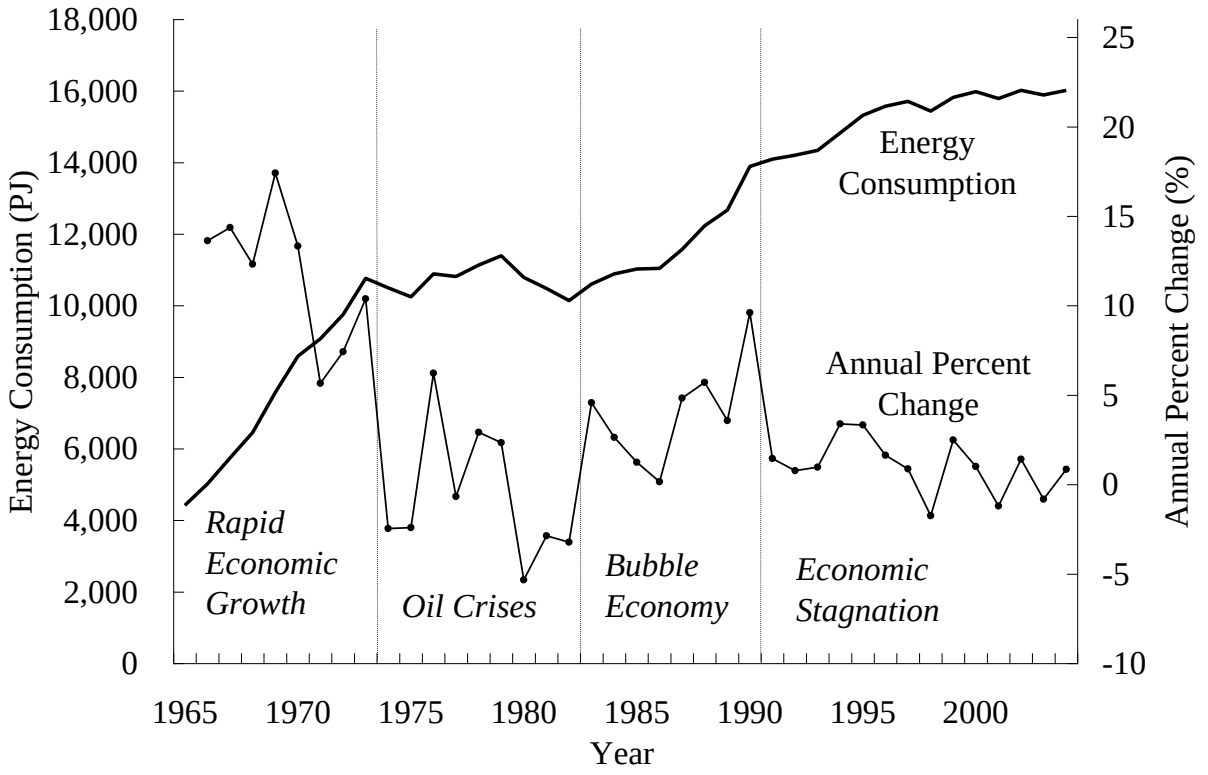
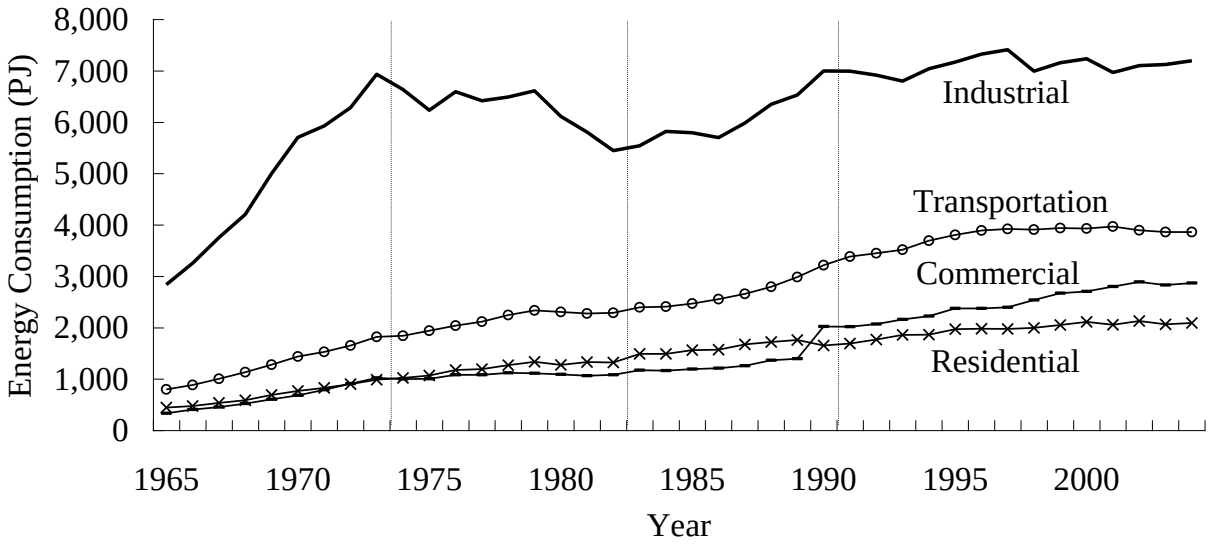
Figure 1　Japan's Aggregate Energy Consumption



(Agency for Natural Resources and Energy)

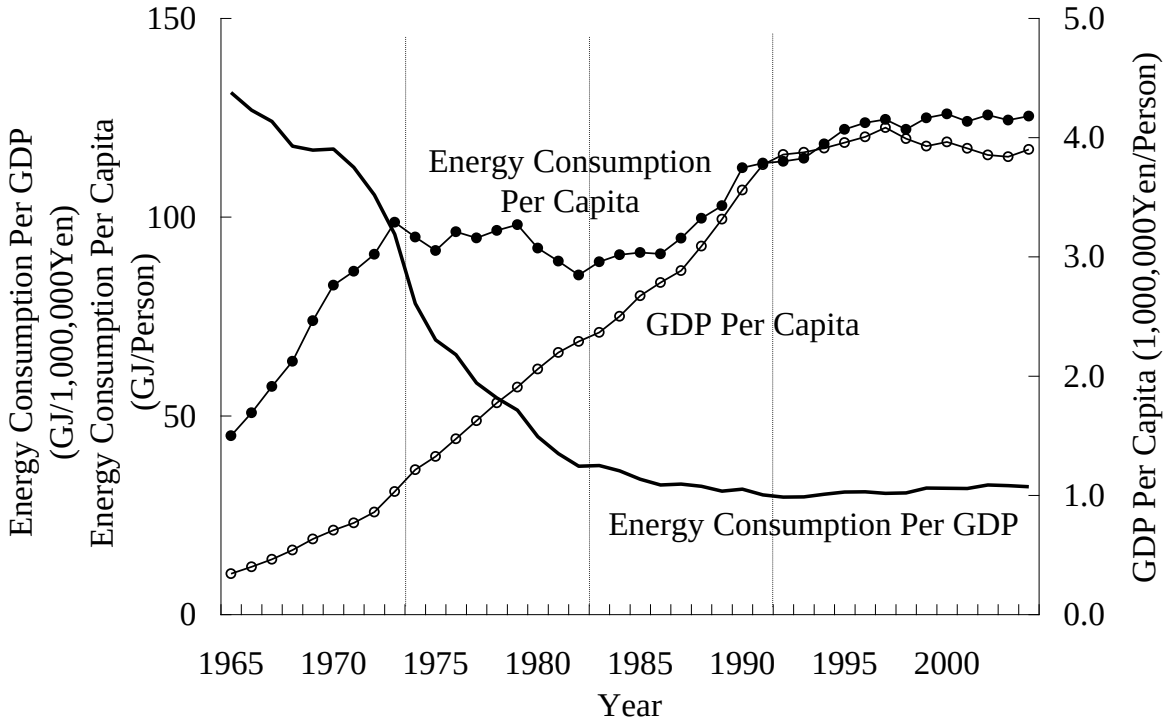
Figure 2　Japan's Energy Consumption by Energy Consuming Sectors



The industrial sector is the manufacturing industry. The transportation sector includes passenger traffic, such as cars and buses, and freight transport, such as land transportation, shipping and airfreight. The commercial sector includes companies' management departments, offices and buildings, and the service industry. The residential sector is all the household energy consumption except transportation, such as private cars.

(Agency for Natural Resources and Energy)

Figure 3　Japan's Energy Consumption and GDP Trends



(Ministry of Internal Affairs and Communications, Cabinet Office, Agency for Natural Resources and Energy)

Figure 4 Decomposition of Aggregate Energy Intensity at the National Level

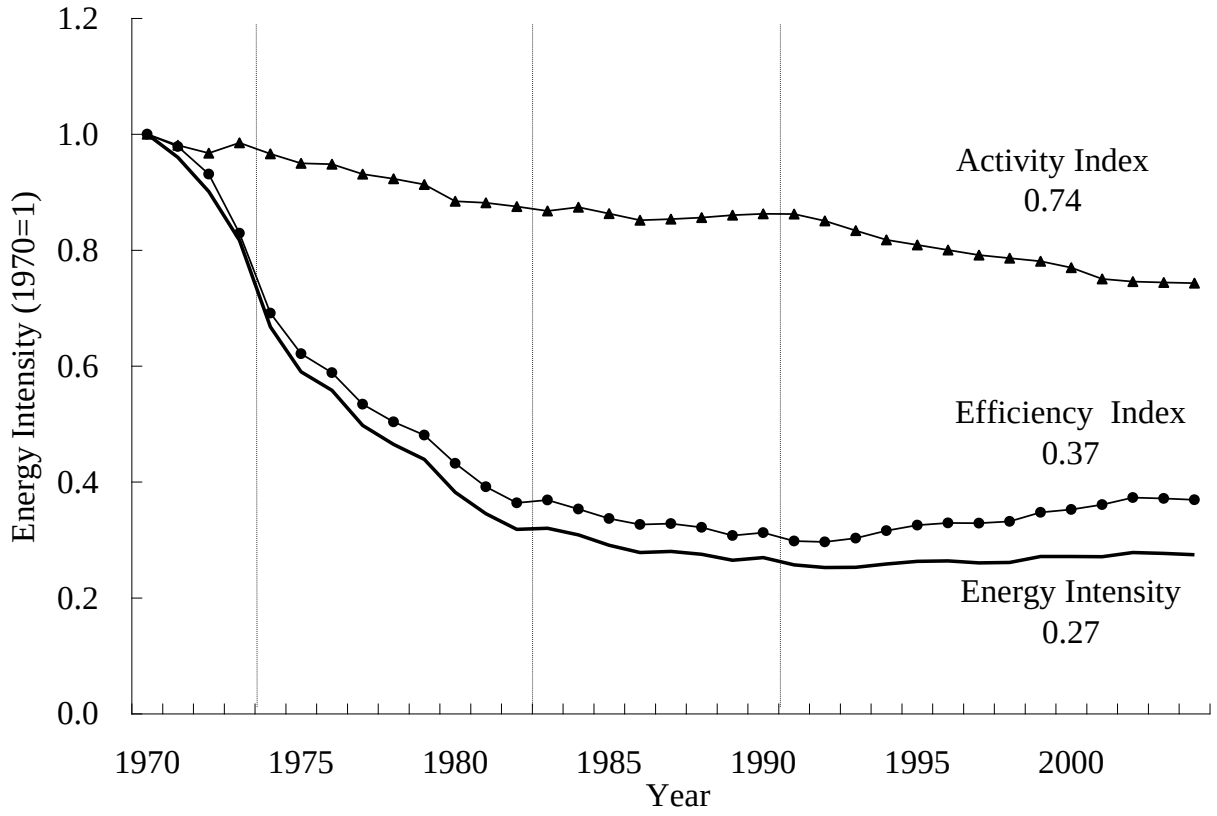
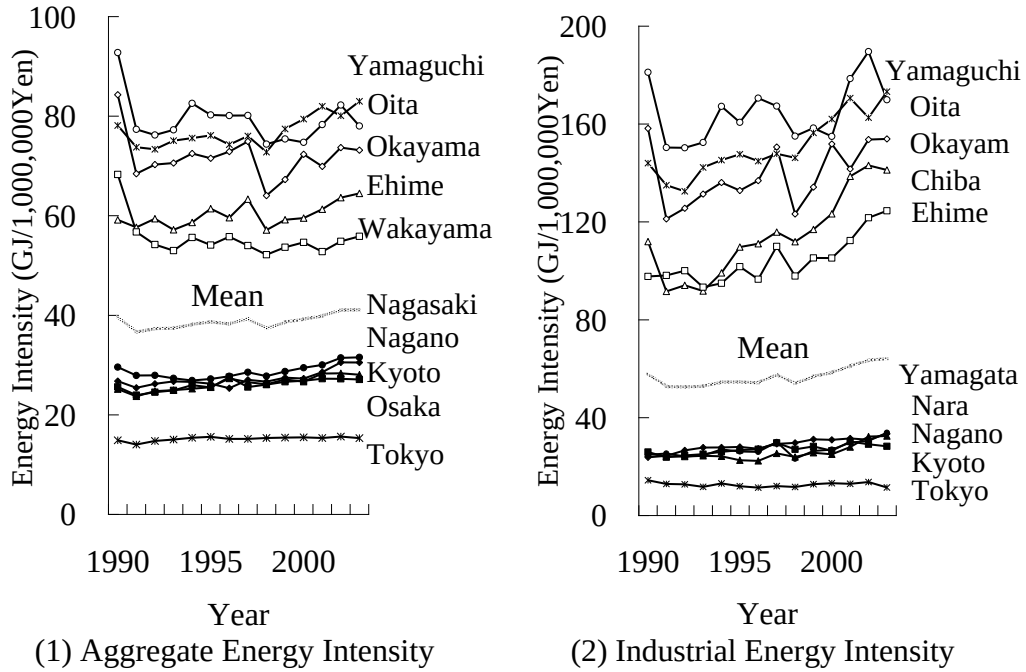
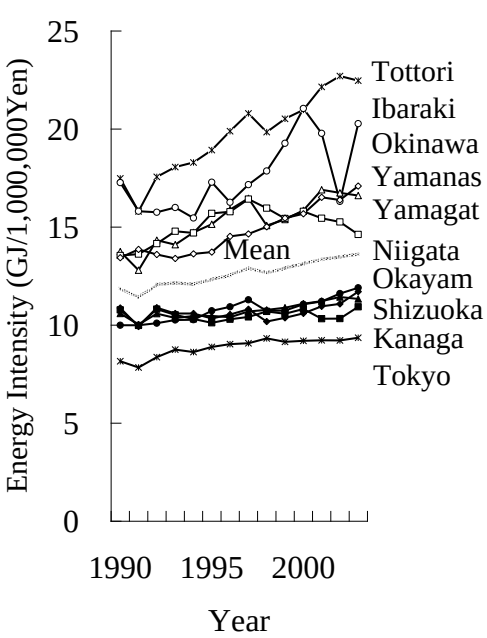


Figure 5　Ten Prefectures with the Lowest and Highest Energy Intensity

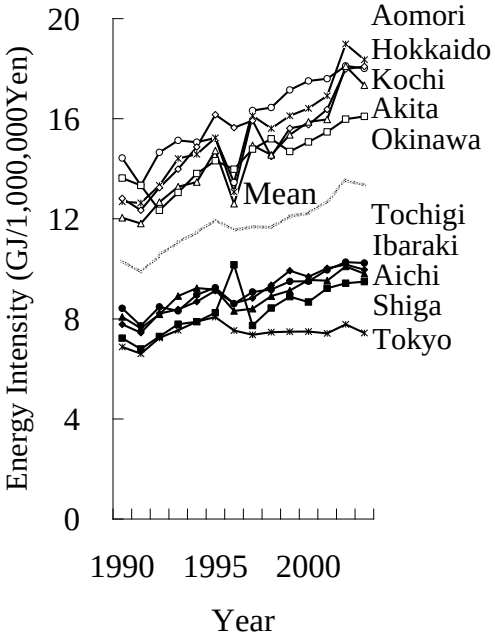


(1) Aggregate Energy Intensity

(2) Industrial Energy Intensity

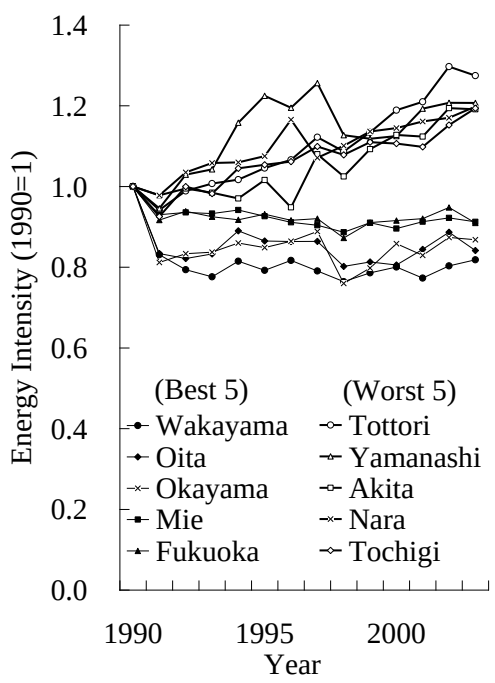


(3) Commercial Energy Intensity

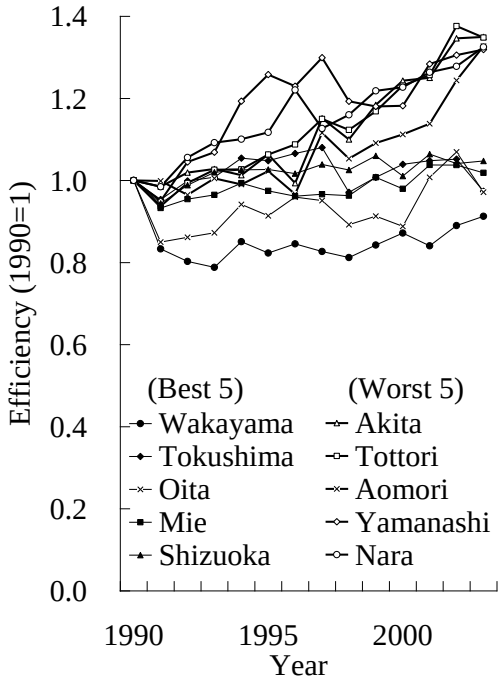


(4) Residential Energy Intensity

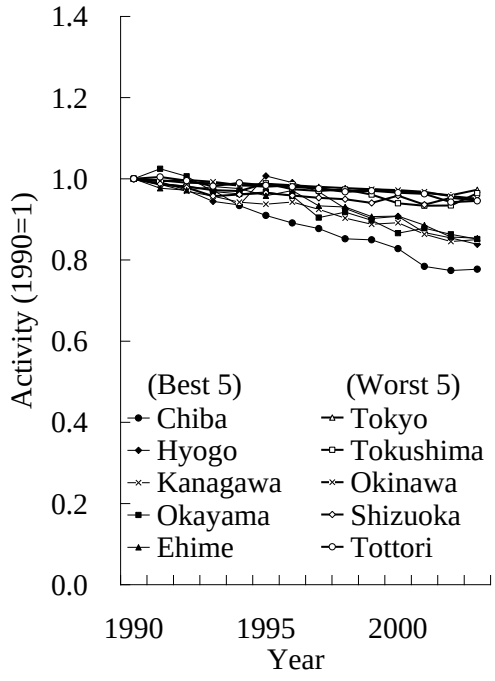
Figure 6 Decomposition of the Prefecture Level Energy Intensity: Ten Prefectures with the Most and Least Reduced Energy Intensity, Efficiency and Activity.



(1) Energy Intensity Index Trend



(2) Efficiency Index Trend



(3) Activity Index Trend

Figure 7 Energy Efficiency of each sectors

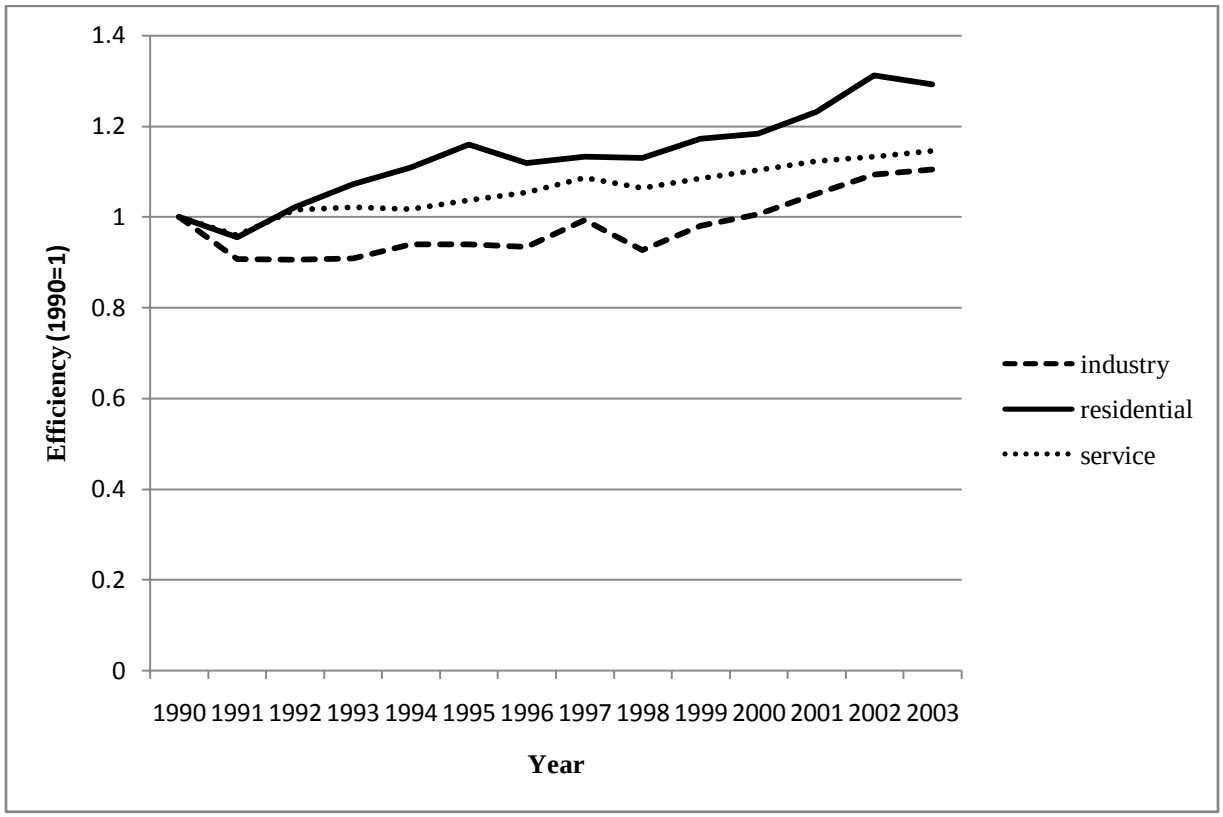


Table 1. The Aggregate Economic Impacts of Carbon Taxes

Carbon Tax ($/Ton)	Emissions (MT)	Abatement (MT)	GDP (one million $)	GDP Change From BaU
0	1166		47966.93	
3	1137.253	28.747	47940.71	-0.019
6	1110.111	55.889	47914.93	-0.038
9	1084.425	81.575	47889.57	-0.057
12	1060.066	105.934	47864.62	-0.075

Table 2. Equivalent Variation of each regions

Carbon Tax ($/Ton)	Equivalent Variation (%)							
	Hokkaido	Tohoku	Kanto	Chubu	Kinki	Chugoku	Shikoku	Kyusyu
0								
3	0.035	0.019	-0.041	-0.018	-0.028	-0.012	0.063	-0.199
6	0.069	0.038	-0.081	-0.036	-0.055	-0.024	0.123	-0.392
9	0.1	0.055	-0.12	-0.054	-0.082	-0.037	0.179	-0.582
12	0.129	0.071	-0.157	-0.071	-0.108	-0.051	0.232	-0.766

Table3. Changes in Gross-of-Tax Commodity Prices (percent)

Carbon Tax ($/Ton)	Coal	Natural Gas	Petroleum	Electric Power	Energy Intensive Manufacture	Transportation	Service	Rest of the Economy
0								
3	2.782	0.828	1.352	0.188	0.02	0.084	-0.032	-0.009
6	5.54	1.65	2.69	0.371	0.039	0.167	-0.064	-0.018
9	8.278	2.466	4.015	0.55	0.057	0.247	-0.095	-0.026
12	10.995	3.277	5.327	0.724	0.075	0.326	-0.125	-0.035

Table4. Changes in Sectoral Activity Level (percent)

Carbon Tax ($/Ton)	Coal	Natural Gas	Petroleum	Electric Power	Energy Intensive Manufacture	Transportation	Service	Rest of the Economy
0								
3	-5.477	-0.874	-3.77	-0.257	-0.063	-0.111	-0.017	-0.027
6	-10.556	-1.726	-7.38	-0.506	-0.123	-0.22	-0.035	-0.054
9	-15.279	-2.559	-10.841	-0.748	-0.182	-0.325	-0.051	-0.08
12	-19.684	-3.373	-14.164	-0.984	-0.239	-0.428	-0.068	-0.105

Table5. Changes in Final Consumption by Commodity (percent)

Carbon Tax ($/Ton)	Coal	Natural Gas	Petroleum	Electric Power	Energy Intensive Manufacture	Transportation	Service	Rest of the Economy
0								
3	-2.753	-0.868	-1.381	-0.235	-0.067	-0.132	-0.015	-0.039
6	-5.339	-1.716	-2.712	-0.464	-0.133	-0.261	-0.031	-0.077
9	-7.775	-2.544	-3.995	-0.687	-0.197	-0.387	-0.046	-0.114
12	-10.073	-3.353	-5.234	-0.903	-0.26	-0.51	-0.061	-0.151

Table6. Sensitivity Results

	Elasticity=1	Elasticity=1.2	Elasticity=0.8
Coal	-19.684	-21.088	-18.246
Petroleum	-14.164	-15.726	-12.57
Natural Gas	-3.373	-3.628	-3.113
Electric Power	-0.984	-1.404	-0.556
Transportation	-0.428	-0.479	-0.377
Energy Intensive Manufacture	-0.239	-0.277	-0.202
Rest of the Economy	-0.105	-0.122	-0.088
Service	-0.068	-0.086	-0.049

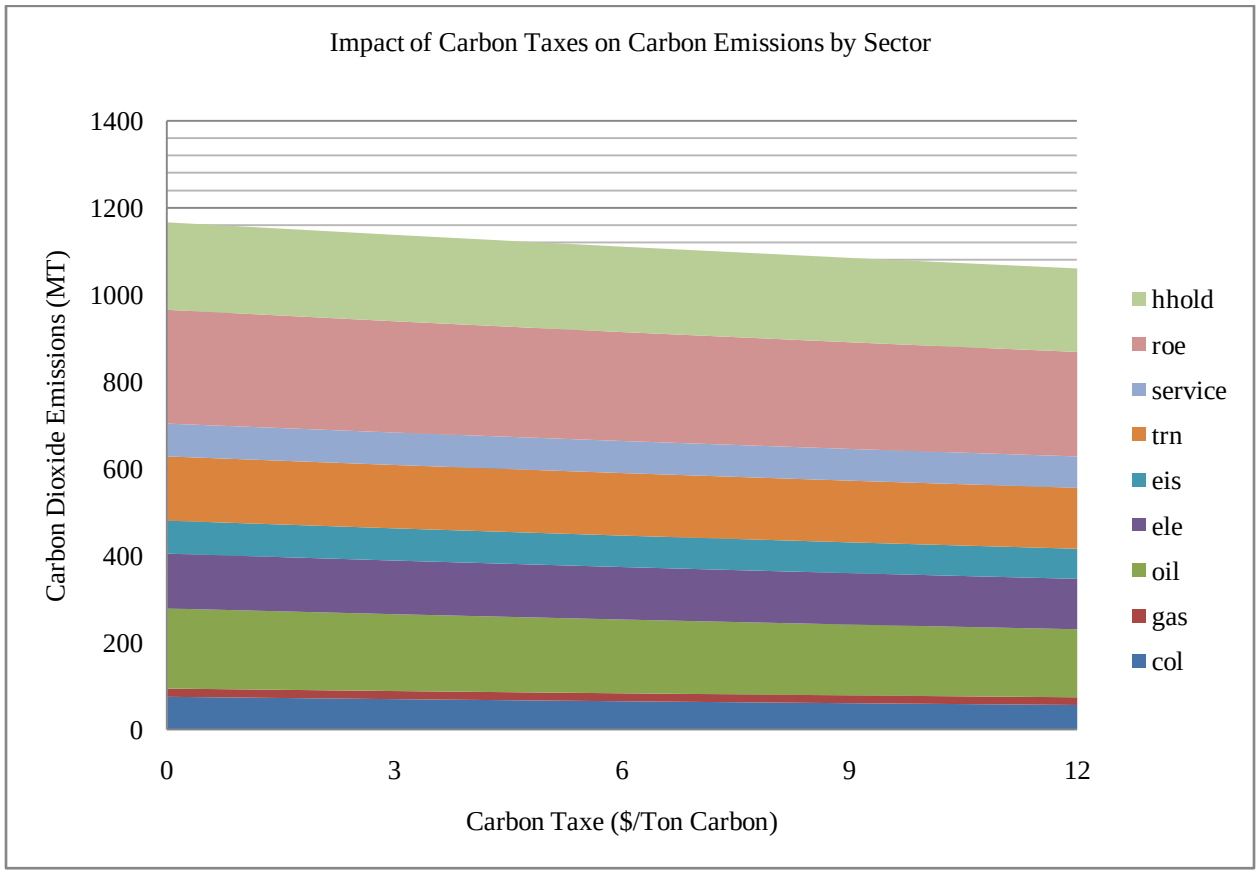



Figure8. Impact of Carbon Taxes on Carbon Emissions by Sector