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Abstract

Many studies of climate policy are based on computable general equilibrium (CGE) modeling. The simulation results and conclusions reached by these models depend on the size of the parameters specified. In particular, the substitution elasticities between production factors have a major influence. Therefore, in order to obtain reliable simulation results we should employ empirical evidence gathered on the substitution elasticities. Unfortunately, in many instances, the lack of econometric analysis means we must specify these key parameters based on existing work or borrow them from prominent modeling exercises. In this study, we estimate nested constant elasticity of substitution (CES) production functions using panel data for OECD countries to help improve the reliability of CGE models for climate policy. Our results show higher values for substitution elasticities closely related to energy inputs for energy-intensive industries and lower values for other industries compared to the conventional values often used in existing models. With the new parameters estimated, we find that conventional parameters could overestimate the necessary carbon price by 44%, and obtain evidence of different distributions of CO_2 emission reduction costs across industries.

JEL classification: D58, Q43, Q54

Key words: Substitution elasticities, CGE modeling, Climate policy

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1 Introduction

An abundant climate policy literature draws on computable general equilibrium (CGE) modeling. The quantitative and qualitative results found using these models, and, therefore, their conclusions, depend on the size of various parameters specified. In particular, substitution elasticities between production factors have a major influence and so excessively high (low) elasticities may bring about under (over) estimation of the impact of climate policy. As a result, we should carefully choose the size of these parameters using empirical evidence. However, there are few econometric studies on the parameters in CGE models available for climate policy analysis. Therefore, we usually have to specify these values based on existing studies from the 1980s or 1990s or borrow conventional values used as defaults in well-known models such as the Global Trade Analysis Project – Energy substitution (GTAP–E) model.[1] Clearly, further econometric analysis is required to specify the parameters in CGE models anew using the latest available datasets.

Some econometric studies on Armington elasticities in CGE models for international trading analysis were found, but we can only cite two studies on the structure of production factors and energy inputs used in climate policy models. Van der Werf (2007) investigated the production structures of CGE models for climate policy using industry-level data from 12 OECD countries and found that the Capital Labor–Energy (KL–E)[2] structure fits the data best. On this basis, they could reject Cobb–Douglas functions for each stage of the nesting structures. Balistreri et al. (2001) estimated the substitution elasticities between capital and labor for 28 industries in the US to use in CGE models. They found that they could not reject unit elasticities for 20 of the 28 industries and could not reject zero elasticities for seven of these. One of their important findings was that we could start simulations with Cobb–Douglas functions.

We use three methodologies to specify the parameters in CGE models. The first is the classic econometric approach (Van der Werf (2007), Balistreri et al. (2001), and Zhang and Verikios (2006)[3]). The second is validation, under which we assess the reproducibility of the model parameters. The final methodology is the maximum entropy approach which is convenient for developing countries with few and poor datasets (Arndt et al. (2001) and Nganou (2004)). We adopt the first approach in this study because new, reliable data gathered by the EU–KLEMS project of the European Commission in 2007 is available: we also lack the statistical foundation for the second two approaches.

The originality of our study is that we estimate all of the substitution elasticities in the Capital Energy–Labor (KE–L) and KL–E-formed production structures, and assess the probability of over- or underestimates of the impacts calculated by the model employing conventional parameters.

The paper is organized as follows. Section 2 explains the role of substitution elasticities in CGE models of climate policy. Section 3 presents our estimation results obtained by panel data analysis. Section 4

[1] Burniaux and Truong (2002).
[2] Under the KL—E structure, capital and labor combine at the bottom level and energy and capital–labor composite goods combine at the upper level.
[3] Zhang and Verikios (2006) used the GTAP database because the economic data usually available is annual even though the simulation results may relate to impacts three or five years after the change in policy. We could also use the Input--Output tables for Japan compiled every five years. However, we used annual data because we wish to know the elasticities—the percentage change in rates of factor demand caused by the change in relative prices—and we do not think this should be a major obstacle.

evaluates the likelihood of over- or underestimates of CGE models using conventional parameters, and Section 5 concludes.

2 Role of substitution elasticities in CGE models

In this section, we explain the concept of substitution elasticity and its importance in CGE modeling. Figure 1 depicts the framework of general CGE models. Consumers and producers are included in the models. Consumers have utility functions and they purchase goods and services to maximize their welfare. Producers have production functions and produce goods and services using labor and capital to minimize their production costs. In most cases, we assume nested constant elasticity of substitution (CES) functions as their production technologies, meaning that we allow substitution between production factors and intermediate inputs.

We usually illustrate substitution structures using trees as shown in Figure 2. We have two major formed structures of substitutions: the KE–L form and the KL–E form.[4] Under the KE–L-formed structure, capital and energy are combined at the bottom level; and under the KL–E-formed structure, labor and capital are combined at the bottom level. The sigma of each stage determines how easily they can switch from one to the other. For example, σ_{KE} is the degree of the substitution between capital (K) and energy (E): if the relative price of capital and energy P_E/P_K changes by 1%, their relative quantities Q_E/Q_K would change by σ_{KE}%. When $\sigma_{KE}=0$, it means there is no substitution between capital and energy, i.e., it is a Leontief function. If we introduce climate policy components such as a carbon tax and emissions trading, the energy price for producers would become higher when compared to the capital price. Producers could hold the same amount of outputs if the capital works as well as energy, that is, $\sigma=\infty$, but this is unrealistic and it is usually considered that $\sigma<\infty$ between disaggregated goods in CGE models. The smaller σ leads to a more negative impact of the policy implementation because of the difficulty in substitution.

We should also carefully consider the nesting structures of capital, labor and energy. The KE–L form is employed by Burniaux and Truong (2002) (the GTAP–E model) and Van der Mensbrugghe (1994) (the GREEN model). The KL–E form appears to be more popular and is used in Bosetti et al. (2006) (the WITCH model), Manne et al. (1995) (the MERGE model), Paltsev et al. (2005) (the EPPA model) and Takeda (2005). In Van der Werf (2007), the goodness of fit of the nesting structures KL–E, KE–L and Labor Energy–Capital (LE–K) was investigated. Based on the R-squared, Van der Werf concluded that the KL–E structure mostly fits the data and the KE–L structure does not fit very well. In Section 4 of this study, we investigate whether we can obtain the same simulation results using these nesting structures together with the statistically founded parameters.

[4] Actually, we found various kinds of nesting structures in previous studies, such as a single-level CES function, but we focus on the two principal forms in this study.

Figure 1: Framework of CGE models

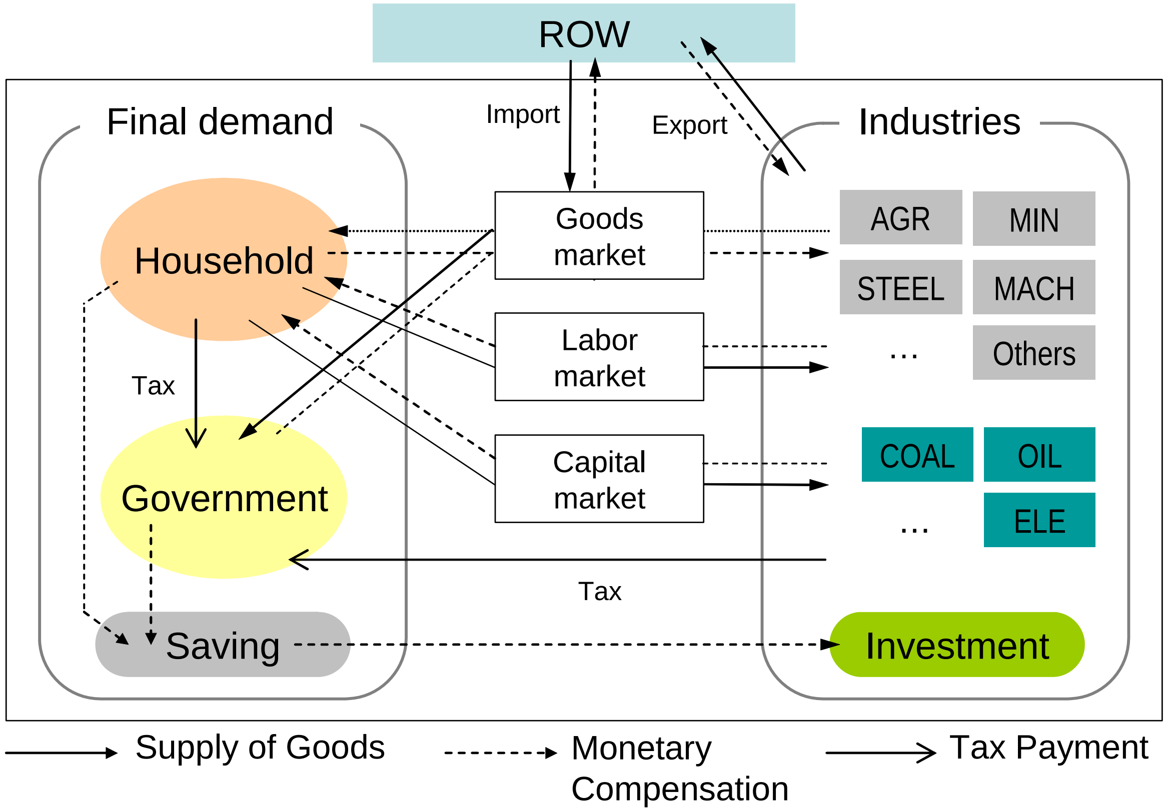
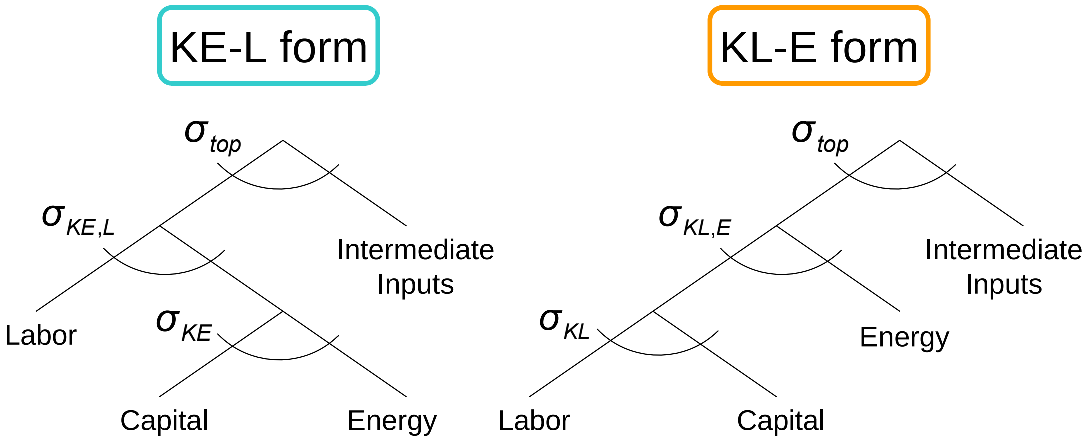


Figure 2: Two major forms of substitution structures



3 Estimation

3.1 The estimation model

In this section, we detail the estimated model. We describe firms' behavior with a cost minimization problem. Assume the three levels of nested CES functions in (3.1) and (3.2) can describe their production structures.

$$KLEM_i = \left[\alpha_{(KL)EM,i} KLE_i^{\frac{\sigma_{(KL)EM,i}-1}{\sigma_{(KL)EM,i}}} + \left(1-\alpha_{(KL)EM,i}\right) M_i^{\frac{\sigma_{(KL)EM,i}-1}{\sigma_{(KL)EM,i}}} \right]^{\frac{\sigma_{KLEM,i}}{\sigma_{(KL)EM,i}-1}} \tag{3.1}$$

$$KLE_i = \left[\alpha_{(KL)E,i} KL_i^{\frac{\sigma_{(KL)E,i}-1}{\sigma_{(KL)E,i}}} + \left(1-\alpha_{(KL)E,i}\right) E_i^{\frac{\sigma_{(KL)E,i}-1}{\sigma_{(KL)E,i}}} \right]^{\frac{\sigma_{(KL)E,i}}{\sigma_{(KL)E,i}-1}} \tag{3.2}$$

$$KL_i = \left[\alpha_{KL,i} K_i^{\frac{\sigma_{KL,ii}-1}{\sigma_{KL,i}}} + \left(1-\alpha_{KL,i}\right) L_i^{\frac{\sigma_{KL,i}-1}{\sigma_{KL,ii}}} \right]^{\frac{\sigma_{KL,i}}{\sigma_{KL,i}-1}} \tag{3.3}$$

K: capital input
L: labor input
E: energy composite goods
M: intermediate inputs
KL: composite goods of capital and labor
KLE: composite goods of capital–labor and energy
σ : substitution elasticity
α : distribution parameter

The first-order condition for each level of cost minimization is derived in equations (3.4)–(3.6).

$$\frac{M_i}{KLE_i} = \left[\frac{1-\alpha_{(KL)EM,i}}{\alpha_{(KL)EM,i}}\right]^{\sigma_{(KL)EM,i}} \left[\frac{PM_i}{PKLE_i}\right]^{\sigma_{(KL)EM,i}} \tag{3.4}$$

$$\frac{E_i}{KL_i} = \left[\frac{1-\alpha_{(KL)E,i}}{\alpha_{(KL)E,i}}\right]^{\sigma_{(KL)E,i}} \left[\frac{PKL_i}{PE_i}\right]^{\sigma_{(KL)E,i}} \tag{3.5}$$

$$\frac{L_i}{K_i} = \left[\frac{1-\alpha_{KL,i}}{\alpha_{KL,i}}\right]^{\sigma_{KL,i}} \left[\frac{PK_i}{PL_i}\right]^{\sigma_{KL,i}} \tag{3.6}$$

Taking logarithms, we obtain the model we estimate as (3.7)–(3.9).

$$\ln\left(\frac{M_i}{KLE_i}\right)_t = \beta_{(KL)EM,i} + \sigma_{(KL)EM,i} \ln\left(\frac{PKLE_i}{PM_i}\right)_t + u_{it} \tag{3.7}$$

$$\beta_{(KL)EM,i} = \sigma_{(KL)EM,i} \ln\left[\frac{1-\alpha_{(KL)EM,i}}{\alpha_{(KL)EM,i}}\right]$$

$$\ln\left(\frac{E_i}{KL_i}\right)_t = \beta_{(KL)E,i} + \sigma_{(KL)E,i} \ln\left(\frac{PKL_i}{PE_i}\right)_t + u_{it} \tag{3.8}$$

$$\beta_{(KL)E,i} = \sigma_{(KL)E,i} \ln\left[\frac{1-\alpha_{(KL)E,i}}{\alpha_{(KL)E,i}}\right]$$

$$ln\left(\frac{L_i}{K_i}\right)_t = \beta_{KL,i} + \sigma_{KL,i}\, ln\left(\frac{PK_i}{PL_i}\right)_t + u_{it} \tag{3.9}$$

$$\beta_{KL,i} = \sigma_{KL,i}\, ln\left[\frac{1-\alpha_{KL,i}}{\alpha_{KL,i}}\right]$$

By the same procedure, we obtain the models to be estimated for the KE–L-formed model in (3.10)–(3.12).

$$\ln\left(\frac{M_i}{KLE_i}\right)_t = \beta_{(KE)LM,i} + \sigma_{(KE)LM,i} \ln\left(\frac{PKLE_i}{PM_i}\right)_t + u_{it} \tag{3.10}$$

$$\beta_{(KE)LM,i} = \sigma_{(KE)LM,i} \ln\left[\frac{1-\alpha_{(KE)LM,i}}{\alpha_{(KE)LM,i}}\right]$$

$$\ln\left(\frac{L_i}{KE_i}\right)_t = \beta_{(KE)L,i} + \sigma_{(KE)L,i} \ln\left(\frac{PKE_i}{PL_i}\right)_t + u_{it} \tag{3.11}$$

$$\beta_{(KE)L,i} = \sigma_{(KE)L,i} \ln\left[\frac{1-\alpha_{(KE)L,i}}{\alpha_{(KE)L,i}}\right]$$

$$\ln\left(\frac{E_i}{K_i}\right)_t = \beta_{KE,i} + \sigma_{KE,i} \ln\left(\frac{PK_i}{PE_i}\right)_t + u_{it} \tag{3.12}$$

$$\beta_{KE,i} = \sigma_{KE,i} \ln\left[\frac{1-\alpha_{KE,i}}{\alpha_{KE,i}}\right]$$

Table 1: Countries and industries included in the panel data

Country	Industry
Austria	Agriculture
Belgium	Mining
Denmark	Food
Spain	Textiles
Finland	Wood
France	Pulp & Paper
Germany	Chemical
Italy	Other Non-metal Mineral
Japan	Basic Metals
Luxembourg	Machinery
Netherland	Electrical Equipment
Sweden	Transport Equipment
United Kindom	Manufacturing
United States	Electricity, Gas and Water
	Construction
	Transport
	Post and Telecommunications
	Financial and Business Services
	Personal Services

We start with the estimation of the parameters at the bottom of each nesting form, σ_{KE} and σ_{KL}. Using the estimation results in the lower stages, we calculate the unit cost of composite goods of labor and capital as (3.13) to estimate the parameters of the upper stages.

$$UnitCost_{KL} = \left[\alpha_{KL} P_K^{\frac{1-\sigma_{KL}}{\sigma_{KL}}} + \left((1-\alpha_{KL}) P_L \right)^{\frac{1-\sigma_{KL}}{\sigma_{KL}}} \right]^{\frac{\sigma_{KL}}{1-\sigma_{KL}}} \tag{3.13}$$

We employ panel data for 14 countries with 19 industries for the period 1995 to 2004 as shown in Table 1. This draws from the dataset compiled by the EU–KLEMS project[5] of the European Commission.

3.2 Estimation results

Table 2 shows our estimation results and the values assumed in existing models. Although we conventionally assume uniform values for each level of nesting structure, our results show variation between industries. For the sigma of the top level, we obtain larger values that lead to smaller negative impacts of policy implementation. On the other hand, the smaller values for σ_{KE-L} and σ_{KL} suggest larger negative impacts of the policy implementation. We have a lower expected σ_{KE} for energy-intensive industries than other industries, but we obtain higher values than one of other industries.

In Table 5 (Appendix 1), we investigate the use of Leontief ($\sigma = 0$) and Cobb–Douglas ($\sigma = 1$) functions. Some engineers and others engaged in energy-intensive industries advocate no substitution between capital and energy and we cannot reject the null hypothesis of $\sigma_{KE} = 0$ in 14 of the 19 industries.

[5] http://www.euklems.net/

Table 2: Comparison of key parameters of main industries

	The KE-L model			The KL-E model		
	Assumed prms		Our estimation	Assumed prms		Our estimation
	σ top			σ top		
Chemical	0.00	<	0.81	0.00	<	0.85
Other Non-metallic Mineral	0.00	<	0.98	0.00	<	0.31
Iron & Steel	0.00	<	1.05	0.00	<	1.17
Machinery	0.00	<	1.15	0.00	<	0.13
Electrical equipment	0.00	<	0.75	0.00	<	0.88
Transport equipment	0.00	<	1.04	0.00	<	0.55
Transport	0.00	<	1.05	0.00	<	0.35
Construction	0.00	<	0.97	0.00	<	1.26
	σ KE-L			σ KL-E		
Chemical	0.80	>	0.34	0.40	>	0.00
Other Non-metallic Mineral	0.80	>	0.21	0.40	<	0.41
Iron & Steel	0.80	>	0.00	0.40	<	0.64
Machinery	0.80	>	0.08	0.40	>	0.29
Electrical equipment	0.80	>	0.33	0.40	<	0.52
Transport equipment	0.80	>	0.43	0.40	<	0.52
Transport	0.80	>	0.47	0.40	>	0.28
Construction	0.80	<	0.94	0.40	<	0.53
	σ KE			σ KL		
Chemical	0.10	>	0.04	1.00	>	0.33
Other Non-metallic Mineral	0.10	<	0.35	1.00	>	0.36
Iron & Steel	0.10	<	0.29	1.00	>	0.22
Machinery	0.20	>	0.12	1.00	>	0.30
Electrical equipment	0.20	<	0.25	1.00	>	0.16
Transport equipment	0.20	>	0.09	1.00	>	0.14
Transport	0.10	<	0.45	1.00	>	0.31
Construction	0.20	>	0.11	1.00	>	0.07

Note: prms stands for parameters.

Many studies, including that of Balistreri et al. (2001), have supported a Cobb–Douglas specification of the substitution between capital and labor. However, our results show considerably lower values than unity, and as in Van der Werf (2007), we reject the null hypotheses of a Cobb–Douglas specification. However, with the elasticities of the upper levels σ_{KE-L} and σ_{KL-E}, we could not reject the null hypotheses of Cobb–Douglas specifications with the exception of for personal services.

Our results show lower σ_{KL} and σ_{KE} compared to Van der Werf (2007) (Table 6 in Appendix 3), even when using data from the same period. One reason is the different method of estimation, especially in that Van der Werf (2007) did not consider the individual effects for each country.

4 Comparison of simulation results with different parameters

In this section, we investigate how we could obtain different results using the parameters estimated in the previous section. We prepared four models based on the CGE model in Okagawa and Ban (2007).

4.1 Basic model

We provide an overview of the static CGE model used. The model is conventional; however, we allow for energy substitution. The three agents in the model are industries, the representative household, and the government.

Industries produce goods and services by using primary factors and intermediate inputs. Production processes exhibit constant returns-to-scale and are represented by nested CES functions. Our model incorporates energy substitutions. Firms select each input level to minimize the production cost given the output level. The household, the government, and foreign countries purchase the goods and services produced by domestic industries as intermediate inputs for industries and as final goods. We aggregated the input–output table to 33 industries. There are seven energy industries and 26 non–energy industries as shown in Table 3.

The representative household has a Cobb–Douglas utility function that implies a trade-off between leisure and consumption. The household owns factors of production, and uses its factor income to purchase goods and services from domestic industries and foreign countries to maximize utility. We also assume the half of the day not spent working constitutes leisure, the price of leisure is the opportunity cost of the labor supply, and household savings are exogenous.

The government collects labor, capital, excise, import, and carbon taxes from industries and the household. The government purchases goods and services to maximize a Cobb–Douglas utility function. Government savings are also exogenous.

The primary factors include labor and capital: these are used in conjunction with energy goods and non-energy intermediate goods to produce domestic goods. The labor supply depends on real wages since it is determined by the choice between labor and leisure. The level of capital is constant and the rate of return on capital is endogenous. We assume that both labor and capital markets are perfectly competitive, and that both factors are perfectly mobile between sectors.

Our model is an open economy model. Imports and exports are endogenously determined by the prices of domestic goods and services relative to world prices. Foreign countries are treated as a single region termed the 'rest of the world'. World goods and services prices are constant. We use the Armington assumption for explaining trade in identical goods and services. This means that domestic goods and foreign goods are imperfect substitutes. The exchange rate adjusts to balance the current account.

We assume that CO_2 emissions are proportional to fossil fuel inputs in each industry. This means that the demand for fossil fuels is synonymous with the demand for CO_2 emissions. By restricting CO_2 emissions, the household, industries, and the government incur emission costs when using fossil fuel inputs. The government collects these additional emission costs in the form of carbon tax revenues.

Table 3: Industries

Fossil fuel	Manufacturing		Service	
Coal	Agriculture	Iron and steel	Construction	Telecom
Oil	Mining	Metal products	Water	Public services
Gas	Foods	Machine	Waste	Private services
Coal products	Textiles	Electric machinery	Commerce	Business services
Oil products	Pulp and wood	Transport machinery	Financial services	Others
Gas distribution	Chemical	Recycle	Real estate	
Electric power	Clay	Other manufacturing	Transportation	

In our model, CO_2 abatement is essentially achieved through three types of substitution.[6] When the introduction of a carbon tax raises energy costs, agents substitute less-CO_2-intensive fuels, such as natural gas, for CO_2-intensive fuels, such as coal (this represents interfuel substitution.) Agents also substitute energy-composites goods for capital and labor (this represents interfactor substitution.) Depending on CO_2 intensity, an increase in the relative price of CO_2-intensive goods and services lowers the relative demand for CO_2-intensive goods (this represents intergoods substitution.)

We constructed our model using the software "GAMS/MPSGE" using the data in the most recent input–output table (2000).[7] To calculate the CO_2 emissions coefficient, we use the Energy Balance table and the Energy and GHGs Emissions Data of Japan.[8, 9]

4.2 Assumptions of parameters for comparison

Based on the model explained, we prepare four CGE models with the following structures of interfactor substitution.

(1) a KE–L-formed structure with the parameters assumed in existing models

(2) a KE–L-formed structure with the parameters estimated in the previous section

(3) a KL–E-formed structure with the parameters assumed in existing models

(4) a KL–E-formed structure with the parameters estimated in the previous section

The common goal of the four simulations is CO_2-emission reduction of 13% to meet Japan's Kyoto target.[10]

[6] The economy will contract if it is impossible to reduce CO_2 sufficiently using substitution.
[7] Ministry of Internal Affairs and Communications.
[8] Agency for Natural Resources.
[9] National Institute for Environmental Studies.
[10] Japan's Kyoto target is to reduce CO_2 emissions to 2.1% below the 1990 level, taking into account carbon sinks. According to "Outlook on Energy Demand and Supply in 2030", Japan's total CO_2 emissions were 286 million t-C in 1990, and are expected to increase by 322 million t-C in 2010. This implies that Japan has to reduce CO_2 emissions to 13% below their 2010 level.

4.3 Comparison of simulation results

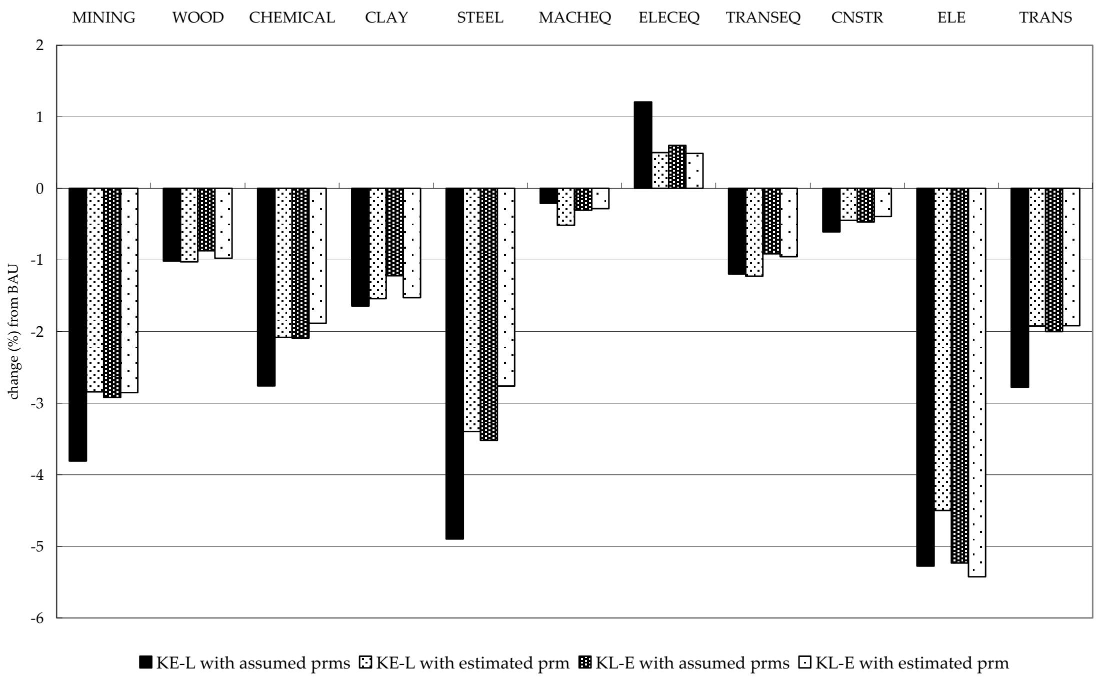
Table 4 shows the results for the macroeconomic impacts. The carbon price calculated by the KE–L-formed model with conventional parameters is much higher when compared to the model with new parameters. This suggests that we could overestimate the necessary carbon tax rate by 44% if we follow conventional values of key parameters for the KE–L models. As for the KL–E-formed models, we only overestimate the carbon price by 3% and we could say their results are similar. The carbon price calculated by the KE–L-formed model is 9.2% higher than that of the KL–E-formed model.

Table 4: Macroeconomic impacts

	Consumption (%)	Factor price (%)		GDP (%)	EV (%)	Carbon price (USD/t-C)
		Labor	Capital			
KE-L with assumed prms	0.021	–0.300	–2.300	–1.100	–0.186	170.6
KE-L with estimated prms	–0.008	–0.400	–1.100	–0.787	–0.164	118.9
KL-E with assumed prms	–0.024	–0.500	–0.700	–0.756	–0.163	111.9
KL-E with estimated prms	–0.012	–0.400	–0.900	–0.728	–0.150	108.9

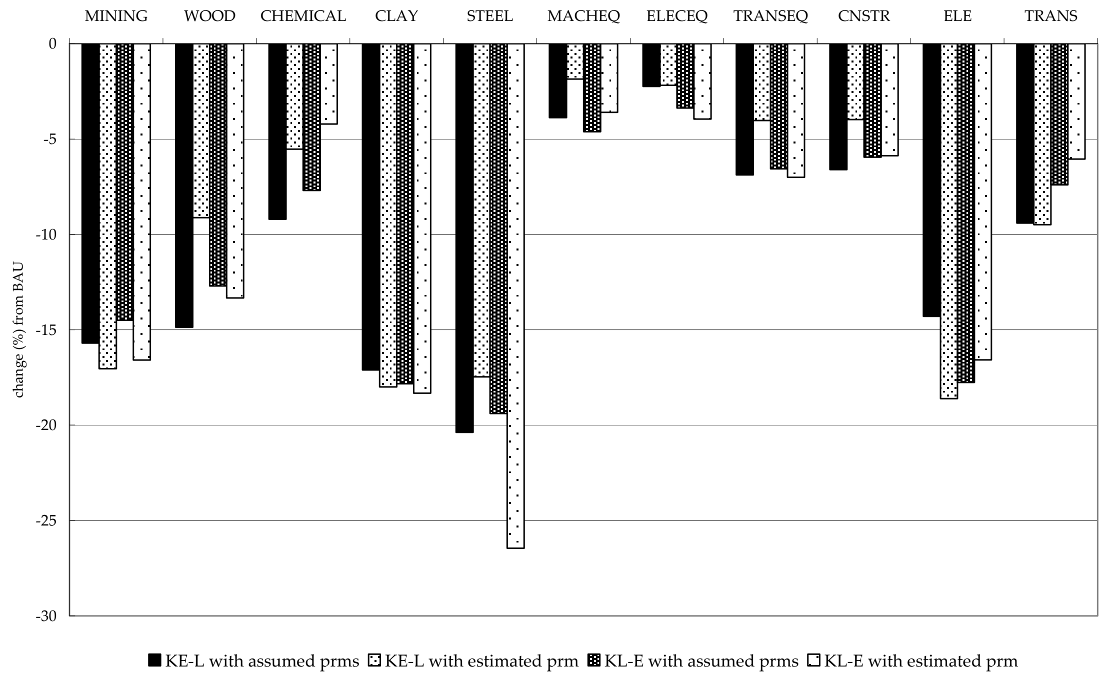
Note: prms stands for parameters.

Figure 3: Output change from the BAU case



Note: prms stands for parameters.

Figure 4: CO_2 emissions change from the BAU case



Note: prms stands for parameters.

Figure 3 presents the change in output level for the industries. Using the KE–L model with conventional parameters, we obtain larger negative impacts on the output level, especially in energy-intensive industries. This is because we thought it was more difficult for them to substitute capital for energy than they actually can.

Figure 4 shows the change in rate of CO_2 emission for each industry. Each model has different elasticities, especially for directly energy-related elasticities such as σ_{KE} and σ_{KL-E}, and this brings about different distributions of emission reductions over industries for the 13% reduction target.[11] We can see substantial differences in the results of our models. We overestimate the emission reductions by 50% for the chemical industry and underestimate by 150% the reductions for the mining industry. As for the iron and steel industry, the simulation results of the KE–L model and the KL–E model are different. This is because the KL–E model can more easily switch energy to other factors than the KE–L model.

[11] Table 7 in Appendix 3 shows the impact on output levels and CO_2 emissions for all industries.

5 Conclusions

In this study, we reestimated the substitution elasticities to help improve the reliability of CGE modeling of climate policy. For the substitution elasticities closely related to energy inputs, we obtained higher values in energy-intensive industries and lower values in other industries when compared to the assumed parameters in existing models. By comparison of the simulation results with different parameters, we found that the macroeconomic impact of climate policy could be potentially overestimated with conventional parameters. We also found differences in the distribution of the burden of CO_2-emission reductions across industries. Using statistically estimated elasticities, the KE–L-formed model evaluates the impact of Kyoto's 13% emission reductions by 9.2% more than the KL–E-formed model.

Appendix 1

Table 5: Estimation results

Industry	K, L				E, KL				M, S				(KL)E, (MS)			
	coefficient	std. error	P (H0: σ =0)	P (H0: σ =1)	coefficient	std. error	P (H0: σ =0)	P (H0: σ =1)	coefficient	std. error	P (H0: σ =0)	P (H0: σ =1)	coefficient	std. error	P (H0: σ =0)	P (H0: σ =1)
Agriculture	0.023	0.0131	0.83	0.00	0.516	0.0861	0.81	0.82	–0.027	0.0491	0.97	0.00	0.392	0.3989	0.42	0.21
Mining	0.139	0.0396	0.43	0.00	0.553	0.0533	0.79	0.83	0.309	0.1454	0.00	0.83	0.729	0.1411	0.92	0.08
Food	0.382	0.0442	0.00	0.00	0.395	0.1290	0.85	0.77	–0.507	0.1178	0.00	0.00	0.329	0.1083	0.43	0.11
Textiles	0.161	0.0275	0.35	0.00	0.637	0.1294	0.00	0.07	0.597	0.1378	0.00	0.02	0.722	0.0987	0.01	0.30
Wood	0.087	0.0409	0.49	0.00	0.456	0.1762	0.82	0.79	0.115	0.1602	0.59	0.00	0.695	0.0967	0.03	0.35
Pulp & Paper	0.381	0.0673	0.00	0.00	0.211	0.1001	0.92	0.71	–0.564	0.1864	0.00	0.00	0.187	0.1136	0.48	0.00
Chemical	0.334	0.0444	0.00	0.00	–0.065	0.0572	0.98	0.63	0.082	0.1081	0.58	0.00	0.848	0.1638	0.01	0.63
Other Non-Metallic Mineral	0.358	0.0399	0.00	0.00	0.411	0.0781	0.84	0.78	0.191	0.1399	0.09	0.00	0.306	0.1091	0.13	0.00
Basic Metals	0.220	0.0244	0.08	0.00	0.644	0.1121	0.76	0.87	0.253	0.1575	0.14	0.00	1.173	0.1294	0.00	0.55
Machinery	0.295	0.0291	0.00	0.00	0.292	0.1112	0.89	0.75	0.459	0.1151	0.00	0.00	0.130	0.1497	0.72	0.01
Electrical Equipment	0.163	0.0270	0.34	0.00	0.524	0.1386	0.82	0.84	0.359	0.1002	0.14	0.01	0.876	0.0761	0.01	0.73
Transport Equipment	0.144	0.0362	0.35	0.00	0.519	0.0917	0.83	0.84	1.087	0.1342	0.00	0.63	0.548	0.0900	0.17	0.26
Manufacturing	0.046	0.0269	0.81	0.00	0.529	0.1387	0.80	0.82	0.309	0.1454	0.03	0.00	0.406	0.0805	0.26	0.10
Electricity, Gas and Water	0.460	0.0692	0.00	0.00	0.256	0.1181	0.90	0.73	0.391	0.1603	0.08	0.01	–0.040	0.1509	0.92	0.01
Construction	0.065	0.0215	0.57	0.00	0.529	0.1110	0.81	0.83	–1.183	0.2903	0.00	0.00	1.264	0.1731	0.00	0.43
Tranport	0.310	0.0573	0.01	0.00	0.281	0.0860	0.90	0.74	0.331	0.1014	0.03	0.00	0.352	0.1785	0.25	0.03
Pst and Telecommunications	0.370	0.0641	0.06	0.00	0.518	0.1636	0.81	0.83	0.711	0.0805	0.04	0.00	0.654	0.1891	0.06	0.31
Financial and Business Services	0.264	0.0345	0.00	0.00	0.320	0.0646	0.88	0.76	–0.036	0.1059	0.85	0.00	0.492	0.0753	0.02	0.02
Personal Services	0.316	0.0560	0.00	0.00	0.784	0.0470	0.00	0.05	0.132	0.0970	0.27	0.00	0.902	0.0922	0.02	0.80

Industry	K, E				KE, L				M, S				(KE)L, (MS)			
	coefficient	std. error	P (H0: σ =0)	P (H0: σ =1)	coefficient	std. error	P (H0: σ =0)	P (H0: σ =1)	coefficient	std. error	P (H0: σ =0)	P (H0: σ =1)	coefficient	std. error	P (H0: σ =0)	P (H0: σ =1)
Agriculture	0.029	0.0213	0.91	0.00	0.547	0.0456	0.82	0.85	–0.027	0.0491	0.97	0.00	0.998	0.0230	0.00	0.99
Mining	0.535	0.0453	0.16	0.23	0.341	0.0752	0.88	0.76	0.309	0.1454	0.00	0.83	0.349	0.1560	0.57	0.29
Food	0.391	0.0909	0.04	0.00	0.286	0.0592	0.90	0.76	–0.507	0.1178	0.00	0.00	0.681	0.0724	0.09	0.42
Textiles	0.170	0.0442	0.57	0.01	0.467	0.2794	0.83	0.81	0.597	0.1378	0.00	0.02	1.023	0.0602	0.00	0.62
Wood	0.052	0.0586	0.89	0.01	–0.112	0.1043	0.96	0.60	0.115	0.1602	0.59	0.00	0.944	0.0576	0.00	0.86
Pulp & Paper	0.372	0.0616	0.16	0.02	0.163	0.1028	0.94	0.70	–0.564	0.1864	0.00	0.00	0.831	0.0717	0.00	0.54
Chemical	0.038	0.0430	0.84	0.00	0.344	0.0687	0.87	0.76	0.082	0.1081	0.58	0.00	0.808	0.0380	0.00	0.40
Other Non-Metallic Mineral	0.350	0.0455	0.02	0.00	0.207	0.0705	0.92	0.72	0.191	0.1399	0.09	0.00	0.987	0.1023	0.00	0.83
Basic Metals	0.290	0.0386	0.16	0.00	–0.170	0.0895	0.94	0.60	0.253	0.1575	0.14	0.00	1.050	0.0613	0.00	0.86
Machinery	0.118	0.0566	0.56	0.00	0.082	0.1000	0.97	0.70	0.459	0.1151	0.00	0.00	1.149	0.0568	0.00	0.63
Electrical Equipment	0.246	0.0690	0.44	0.00	0.331	0.1175	0.90	0.79	0.359	0.1002	0.14	0.01	0.745	0.0876	0.03	0.46
Transport Equipment	0.091	0.0456	0.45	0.00	0.431	0.1259	0.87	0.83	1.087	0.1342	0.00	0.63	1.037	0.1177	0.01	0.93
Manufacturing	0.102	0.0328	0.70	0.00	0.251	0.0478	0.92	0.76	0.309	0.1454	0.03	0.00	1.046	0.0956	0.00	0.90
Electricity, Gas and Water	0.396	0.0935	0.22	0.06	0.375	0.1103	0.85	0.76	0.391	0.1603	0.08	0.01	0.418	0.2107	0.28	0.13
Construction	0.105	0.0451	0.70	0.00	0.938	0.1564	0.71	0.98	–1.183	0.2903	0.00	0.00	0.974	0.0617	0.00	0.93
Tranport	0.449	0.0645	0.10	0.04	0.466	0.0704	0.81	0.78	0.331	0.1014	0.03	0.00	1.045	0.0553	0.00	0.88
Pst and Telecommunications	0.288	0.1215	0.51	0.11	0.345	0.0900	0.87	0.76	0.711	0.0805	0.04	0.00	0.439	0.1665	0.21	0.11
Financial and Business Services	0.271	0.0533	0.03	0.00	0.370	0.0607	0.87	0.78	–0.036	0.1059	0.85	0.00	0.854	0.0574	0.00	0.53
Personal Services	0.654	0.0415	0.00	0.13	0.793	0.0647	0.00	0.02	0.132	0.0970	0.27	0.00	1.029	0.0754	0.00	0.91

Appendix 2

Table 6: Comparison with previous studies

	K, L			KL, E	
	Okagawa & Ban (2008)	Van der Werf (2007)	Balisteri et al. (2001)	Okagawa & Ban (2008)	Van der Werf (2007)
Basic metals	0.22	0.59	0.09	0.64	0.62
Construction	0.07	0.22	0.19	0.53	0.29
Food & Tob.	0.38	0.46	0.02	0.39	0.40
Transport Eq.	0.14	0.44	0.05	0.52	0.16
Non-metal. Min.	0.36	0.45	0.06	0.41	0.25
Paper etc.	0.38	0.37	0.05	0.21	0.40
Textiles etc.	0.16	0.27	0.02	0.64	0.29

	K, E		KE, L	
	Okagawa & Ban (2008)	Van der Werf (2007)	Okagawa & Ban (2008)	Van der Werf (2007)
Basis metals	0.29	0.88	-0.17	0.83
Construction	0.10	0.99	0.94	0.95
Food & Tob.	0.39	0.99	0.29	0.92
Transport Eq.	0.09	1.00	0.43	0.98
Non-metal. Min.	0.35	1.00	0.21	0.94
Paper etc.	0.37	0.97	0.16	0.81
Textiles etc.	0.17	1.00	0.47	1.04

Appendix 3

Table 7: Industry impacts calculated using the four models

	Output				CO_2 emissions			
	KE-L		KL-E		KE-L		KL-E	
	Assumed prms	Estimated prms	Assumed prms	Estimated prms	Assumed prms	Estimated prms	Assumed prms	Estimated prms
AGRI	–0.25	–0.67	–0.65	–0.56	–11.92	–3.96	–14.94	–17.86
MINING	–3.81	–2.84	–2.92	–2.85	–15.70	–17.05	–14.50	–16.59
COAL	–13.86	–14.25	–14.58	–14.65	-	-	-	-
OIL	–9.33	–8.27	–7.88	–7.09	-	-	-	-
GAS	–8.11	–11.71	–11.27	–10.46	-	-	-	-
FOOD	–0.06	–0.29	–0.31	–0.26	–7.21	–7.71	–7.71	–7.36
TEXTILE	–0.09	–0.23	–0.18	–0.22	–7.87	–5.39	–7.69	–9.98
WOOD	–1.02	–1.02	–0.87	–0.98	–14.87	–9.12	–12.70	–13.33
OMFG	–0.24	–0.48	–0.32	–0.38	–7.41	–4.46	–7.16	–8.05
CHEMICAL	–2.76	–2.08	–2.09	–1.89	–9.21	–5.54	–7.70	–4.22
OL_P	–9.42	–8.08	–7.68	–6.92	–10.58	–9.14	–8.72	–7.95
CL_P	–7.96	–6.39	–7.69	–8.51	–9.80	–7.76	–8.95	–9.74
CLAY	–1.65	–1.54	–1.22	–1.53	–17.11	–18.00	–17.83	–18.32
STEEL	–4.90	–3.40	–3.52	–2.76	–20.38	–17.48	–19.39	–26.46
METAL	–1.20	–1.52	–0.96	–1.35	–5.29	–3.71	–5.14	–6.03
MACHEQ	–0.21	–0.52	–0.30	–0.28	–3.88	–1.86	–4.62	–3.60
ELECEQ	1.21	0.50	0.60	0.49	–2.24	–2.18	–3.38	–3.95
TRANSEQ	–1.20	–1.23	–0.91	–0.96	–6.88	–4.03	–6.57	–7.01
RECYCLE	–7.98	–5.29	–5.93	–4.60	–15.54	–11.18	–10.97	–9.60
CNSTR	–0.61	–0.45	–0.47	–0.39	–6.61	–3.98	–5.95	–5.87
ELE	–5.28	–4.50	–5.23	–5.43	–14.30	–18.61	–17.77	–16.58
GASD	–3.92	–3.59	–3.70	–4.12	–18.74	–16.00	–15.68	–15.65
WATER	–0.65	–0.59	–0.64	–0.56	–7.90	–7.39	–7.07	–5.86
WASTE	–2.01	–1.48	–1.49	–1.35	–40.47	–34.82	–34.90	–34.40
CMMRC	0.14	–0.00	0.03	–0.01	–7.77	–6.21	–7.54	–7.39
FINSRV	–0.02	–0.08	–0.27	–0.13	–7.75	–6.69	–7.73	–6.74
DWELLING	1.57	0.71	0.39	0.58	–6.85	–5.43	–7.33	–7.07
TRANS	–2.78	–1.92	–2.00	–1.92	–9.41	–9.50	–7.40	–6.05
TELECOM	0.08	–0.14	–0.12	–0.15	–7.85	–6.97	–7.57	–8.26
PUBSRV	–0.79	–0.61	–0.54	–0.53	–10.23	–7.94	–8.22	–8.01
BUSSRV	–0.30	–0.27	–0.40	–0.30	–7.41	–6.43	–7.64	–6.55
PRVSRV	0.19	0.04	–0.02	0.02	–7.68	–9.56	–7.26	–9.91
OTHERS	–0.52	–0.56	–0.56	–0.49	–7.51	–5.97	–9.00	–8.75

References

Arndt, C., Robinson, S. and Tarp, F. (2001), “Parameter Estimation For A Computable General Equilibrium Model: A Maximum Entropy Approach”, Economic Modeling, 19(3), pp. 375–398.

Balistreri, E. J., McDaniel, C. A. and Wong, E. V. (2001), “An Estimation of U.S. Industry-Level Capital-Labor Substitution”, Computational Economics 0303001, EconWPA, Washington University.

Bosetti, V., Carraro, C., Galeotti, M., Massetti, E. and Tavoni M. (2006) "WITCH. A World Induced Technical Change Hybrid Model”, The Energy Journal, 27(2), pp. 13–38.

Burniaux, J. M. and Truong T. (2002), "GTAP-E: An Energy-Environmental Version of the GTAP Model," GTAP Technical Papers 923, Center for Global Trade Analysis, Department of Agricultural Economics, Purdue University.

Manne, A., Mendelsohn, M. and Richels, R. (1995), "MERGE - A Model for Evaluating Regional and Global Effects of GHG Reduction Policies", Energy Policy, 23(1), pp. 17–34.

Nganou, J. P. N. (2004), “Estimating the Key Parameters of the Lesotho CGE Model”, International Conference “Input-Output and General Equilibrium: Data, Modeling, and Policy Analysis”, Brussels (Belgium), September 2–4, 2004.

Okagawa, A. and Ban, K. (2007) “Evaluation of Carbon Abatement Policies with Assistance to Carbon-Intensive Industries in Japan”, EcoMod International Conference on Energy and Environmental Modeling, Moscow, Russia.

Paltsev, S., Reilly, J. M., Jacoby, H. D., Eckaus, R. S., McFarland, J., Sarofim, M., Asadoorian, M. and Babiker, M. (2005) “The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Version 4”. MIT Joint Program on the Science and Policy of Global Change, Report No. 125.

Takeda, S. (2005), “The Double Dividend from Carbon Regulation in Japan”, Journal of the Japanese and International Economies, 21(3), pp. 336–364.

Van der Mensbrugghe, D. (1994) “GREEN: The Reference Manual”, OECD Economic Department Working Papers No. 143.

Van der Werf, E. (2007) “Production Functions for Climate Policy Modeling: An Empirical Analysis”, FEEM Working Paper No. 47.2007.

Zhang, X. and Verikios, G. (2006), “Armington Parameter Estimation for a Computable General Equilibrium Model: A Database Consistent Approach”, Economics Discussion Working Papers No. 06–10, The University of Western Australia, Department of Economics.