A Forecast of Energy Demand in Japan Considering Asymmetric Price Elasticities

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Considering asymmetric price elasticities in energy demand functions is an important issue in the field of energy economics. We have estimated past energy demand functions by sector and types of energy in Japan, and confirmed the existence of asymmetric price elasticities in most of the functions. As in the previous studies, when energy prices are falling, price elasticities are insignificant in most of the energy demand functions. Even when energy prices are rising, price elasticities are not significant in many of the functions. We have also constructed a simple energy and economy model to compare future energy demands between the cases with symmetric or asymmetric energy price elasticities. The results show that future energy demand with asymmetric price elasticities is greater than that with symmetric price elasticities. This is because in the asymmetric case, past maximum prices are the most significant factors and price effects will not work unless future energy prices exceed past maximum levels.

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Introduction

While its main purpose has changed over time, forecasting future energy demand remains important. Previously, as a huge energy importing country, estimating how much energy would be needed was the primary purpose of demand forecasts in Japan. Recently, however, devising CO_2 mitigation scenarios to achieve greenhouse gas (GHGs) emission targets decided upon at the third session of the Conference of the Parties (COP3) in 1997 is the most important purpose of demand forecasting. On the other hand, according to population forecasts by the National Institute of Population and Social Security Research (IPSS) in 1997, the total population of Japan will reach its peak in ten years. It is expected that the subsequent decrease in population will bring lower rates of economic growth and decreased energy demand. In this scenario, energy demand forecasting becomes still more important because low growth of energy demand will affect future technological development and capital investment which necessitate long lead-times.

Future energy demand is generally forecasted by using energy demand functions, which are estimated from time-series past records with an econometric approach. In the energy demand functions, energy price elasticities are usually incorporated and it is assumed they are symmetrical with respect to rising and falling energy prices.

However, some researchers have indicated the existence of asymmetry in price elasticities. For example, Walker and Wirl (1993) have investigated the transportation energy demand of three European countries and discovered that energy demands after 1986 are overestimated if the energy demand functions are estimated with the data from 1961 to 1985, when energy prices were rising almost continuously. They explained that this is because an irreversible improvement in energy efficiency occurred during the period of rising prices and the effects of the improvements remained during the period of falling prices as well. Haas and Schipper (1998) have decomposed energy price changes into three components: the maximum price in the past, cumulative price increases and cuts. They then estimated price elasticities in the residential sector of ten OECD countries and found that price elasticities are not the same with respect to rising and falling energy prices and that price elasticities during periods of falling prices are close to zero.

The purpose of this paper is first to investigate whether price elasticities in the Japanese sectoral energy demand by each type of energy are symmetrical or not using the same method as Haas and Schipper. It is expected that estimating the elasticities by each type of energy would bring clearer results than those arrived at by using weighted energy prices. The other purpose is to forecast future energy demands by using both symmetrical and asymmetrical energy demand functions and to compare their results. For these purposes, the substitution between fuels and autonomous efficiency improvements (AEI) are not considered, although they are commonly used in other econometric energy models. Moreover, in cases where the demand of each type of energy is estimated separately, as in this study, estimated AEI parameters include other effects such as fuel substitution by environmental regulation.

2. Methods

The traditional energy demand function with symmetrical price elasticities is written as, Eq. (1):

$$\ln E_t = C + \alpha \ln p_t + \beta \ln Y_t + \delta \ln X_t + \lambda \ln E_{t-1} \qquad (1)$$

where:

E_t = the energy demand in year t;

p_t = the real energy price in year t;

Y_t = the real income in year t;

X_t = other explaining variable in year t;

λ = the coefficient of lagged energy demand.

Next, energy price changes are decomposed into multiplicative form using Haas and Schipper's method, Eq. (2):

$$p_t = p_t^{\max} \bullet p_t^{rec} \bullet p_t^{cut} \qquad (2)$$

where:

$p_t^{\max}$ = the maximum price from the beginning year to the year t;

p_t^{rec} = cumulative price increases from the beginning year to the year t;

p_t^{cut} = cumulative price cuts from the beginning year to the year t.

These three components are calculated by the following equations:

$$p_t^{\max} = \max\{p_0, p_1, \cdots p_t\} \qquad (3)$$

$$p_t^{rec} = \prod_{i=0}^{t} \max\left\{1, \frac{p_{i-1}^{\max}/p_{i-1}}{p_i^{\max}/p_i}\right\} \qquad (4)$$

$$p_t^{cut} = \prod_{i=0}^{t} \min\left\{1, \frac{p_{i-1}^{\max}/p_{i-1}}{p_i^{\max}/p_i}\right\} \qquad (5)$$

Substituting Eq. (2) for Eq. (1) gives the energy demand function with asymmetrical price elasticities:

$$\ln E_t = C + \alpha_{\max} \ln p_t^{\max} + \alpha_{rec} \ln p_t^{rec} + \alpha_{cut} \ln p_t^{cut} + \beta \ln Y_t + \delta \ln X_t + \lambda \ln E_{t-1} \qquad (6)$$

Figure 1 shows an example of a decomposed energy price: past crude oil price in real terms (converted by GDP deflator). The variable $p_t^{\max}$ has not changed since 1982 and current level of p_t is about one fifth of $p_t^{\max}$. It is not expected that $p_t^{\max}$ will make a new record within ten or twenty years from now. The same situation can be seen for many types of energy. It means price elasticity will not work in the energy demand functions for that period, even though $p_t^{\max}$ is significant in Eq. (6).

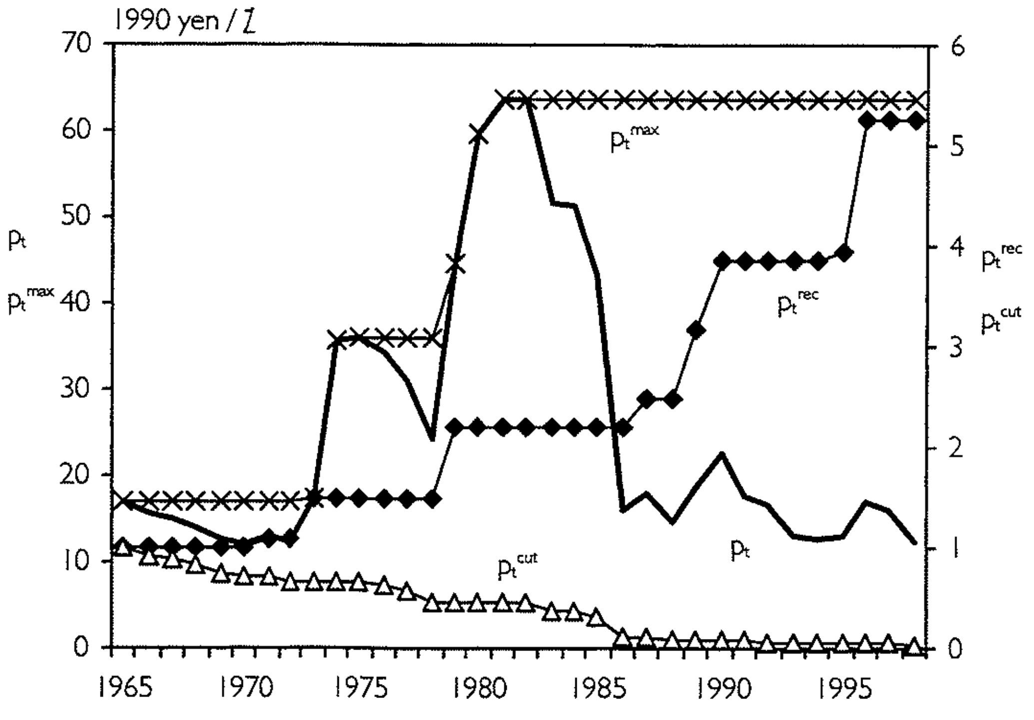

Figure 1: Decomposed Crude Oil Price

3. Estimated Results

We have estimated the energy demand functions for each type of energy using the method previously described. For the equations with asymmetrical price elasticities, only the terms whose coefficients of $p_t^{\max}$, p_t^{rec}, p_t^{cut} are significant, were left.

All of the data related to energy consumption, prices and the economy are derived from the domestic databases of the government. Most of the data are included in EDMC (2000).

Capital stock multiplied by the rate of operation is chosen as Y_t in the industrial sector. It is known that the industrial structure affects energy demand greatly. For example, the machinery industry depends on electricity more heavily than other types of industry, and if the overall percentage share of the machinery industry increases, electricity demands tend to increase. There has been considerable transformation from the raw-material industry to the machinery and service industries during the 70's and 80's in Japan. Taking this into account, the machinery industry's or raw-material industry's percentage shares in total production are included as explaining variables. Real production of the service industry, household disposable income, and real GDP are used as Y_t in the commercial, residential and transportation sectors respectively. Nominal energy prices are deflated by the wholesale price index in the industrial and transportation sectors. On the other hand, they are converted by the deflator of private final consumption expenditures in the commercial and residential sectors.

The results of these estimates for each sector are reported in Table 1. Absolute values of asymmetrical price elasticities are greater than symmetrical values in all of the equations. Among the decomposed energy prices, the maximum prices in the past are most significant in ten of nineteen equations. Cumulative price increases are most significant in six equations. Cumulative price cuts are not significant in all equations. This is the same result as that achieved by Haas and Schipper. In about half of the equations, t-statistics of price elasticities are improved by considering asymmetry. Other important points are the changes in the coefficients and their t-statistics of the lagged energy demand. In most of the equations, both the coefficients and their t-statistics of the lagged energy demand became smaller by considering asymmetry. This means that the significance of the lagged energy demand decreases because energy prices with asymmetric price elasticities increase in significance.

4. Macro-Economy and Energy Model

We have constructed a macro-economy and energy model to forecast future energy demand with the energy demand functions shown previously. It is very simple to get the minimum information needed for this model. The variables and structure are shown in Figure 2. Murota (1984) originally developed the macro-economy block of this model. The main exogenous variables are the dollar exchange rate, crude oil prices and taxes, world imports and wages. The main endogenous variables are capital stock, each component of the GDP, domestic commodity prices and energy prices. During the late 80's, the Japanese economy experienced the so-called "bubble economy," which collapsed in the early 90's. To remove this effect, a bubble dummy is incorporated as an explaining variable for private investment. The equations and estimated results of the macro-economy block are attached in the Appendix. The fitness of regression is acceptable and the final test during 1980 to 1997 shows a 0.6-3.8% error for the variables of the macro-economy block. All energy prices are estimated as functions of a crude oil price in the energy price block. The energy demand block includes the demand functions shown in section 3.

Table 1 Estimated Results of Energy Demand Functions

			α		β		δ			λ		A
Industrial Sector												
	Electricity	α	-0.115	(-5.42)	0.263	(5.69)	Raw-material	0.407	(2.66)	0.508	(7.34)	-0.234
		α_{max}	-0.160	(-5.09)	0.305	(6.15)	Raw-material	0.439	(2.78)	0.484	(6.77)	-0.310
	Coal	α	-0.159	(-1.64)	0.066	(2.31)				0.679	(5.57)	-0.495
		α_{rec}	-0.517	(-1.62)	0.150	(2.36)				0.705	(5.38)	-1.753
	Petroleum	α	-0.177	(-6.81)	0.150	(1.40)	Machinery	-0.281	(-1.14)	0.705	(10.88)	-0.600
		α_{max}	-0.421	(-10.83)	0.311	(6.69)	Raw-material	0.421	(2.52)	0.458	(7.72)	-0.777
	Gas	α	-0.111	(-2.10)	0.082	(2.06)				0.911	(14.16)	-1.247
		α_{rec}	-0.114	(-1.60)	0.123	(1.88)				0.946	(15.80)	-2.111
Commercial Sector												
	Electricity	α	-0.033	(-1.02)	0.368	(2.82)				0.725	(8.95)	-0.120
		α_{max}	-0.081	(-1.34)	0.453	(3.71)				0.688	(8.56)	-0.260
	Coal				0.265	(2.12)				0.722	(6.41)	
	Petroleum	α	-0.099	(-2.10)	0.040	(2.06)				0.760	(14.16)	-0.413
		α_{max}	-0.210	(-4.20)	0.187	(3.55)				0.655	(9.01)	-0.609
	Gas	α	-0.014	(-0.80)	0.108	(1.01)				0.878	(9.85)	-0.115
		α_{rec}	-0.034	(-0.74)	0.118	(1.05)				0.894	(8.75)	-0.321
Residential Sector												
	Electricity	α	-0.088	(-2.67)	0.330	(4.21)				0.723	(14.87)	-0.318
		α_{max}	-0.142	(-1.80)	0.457	(3.83)				0.674	(8.48)	-0.436
	Coal	α	-0.201	(-1.78)	-1.600	(-3.18)				0.528	(3.86)	-0.426
		α_{rec}	-0.215	(-0.67)	-1.705	(-2.39)				0.510	(2.57)	-0.439
	Kerosene	α	-0.023	(-0.48)	0.248	(2.24)				0.625	(6.92)	-0.061
		α_{rec}	-0.231	(-1.55)	0.859	(7.66)						-0.231
	LPG	α	-0.118	(-0.93)	0.120	(1.32)				0.767	(9.67)	-0.506
		α_{rec}	-0.414	(-1.40)	0.455	(3.14)				0.447	(2.55)	-0.749
	Gas	α			0.236	(2.49)				0.743	(10.35)	
		α_{max}	-0.148	(-1.76)	0.665	(4.36)				0.270	(1.71)	-0.203
Transportation Sector												
	Electricity	α	-0.043	(-1.59)	0.236	(2.99)				0.608	(5.53)	-0.110
		α_{max}	-0.157	(-2.32)	0.403	(3.89)				0.475	(3.95)	-0.299
	Gasoline	α	-0.114	(-4.09)	0.031	(0.54)				0.859	(17.24)	-0.809
		α_{max}	-0.766	(-2.88)	0.151	(5.65)				0.800	(22.22)	-3.830
	Diesel Oil	α	-0.095	(-5.11)	0.582	(5.00)				0.546	(7.13)	-0.209
		α_{max}	-0.485	(-2.68)	1.026	(4.85)				0.361	(3.00)	-0.759
	Heavy Oil	α	-0.073	(-1.33)	-0.139	(-2.89)				0.837	(11.45)	-0.448
		α_{max}	-0.107	(-3.12)						0.672	(7.88)	-0.326
	LPG				0.069	(0.95)				0.595	(5.40)	
	Jet Fuel				0.187	(2.15)				0.792	(13.80)	

Notes:

Estimated period: 1973-97 (asymmetric, residential sector), 1968-97 (others).

Figures in parentheses denote t-statistics of coefficients.

Adjusted R-squares are 0.810-0.998 except for coal in the commercial sector and LPG in the transportation sector.

"A" means long run price elasticities calculated by $\alpha/(1-\lambda)$.

Upper value of each type of energy: considering the symmetric price elasticity.

Lower value of each type of energy: considering the asymmetric price elasticity.

Raw-material and machinery mean the share of each industry in total output of industry (excluding service industry).

CP: Private consumption

D: Bubble dummy
(1988-92: 1, other years: 0)
EX: Exports
IM: Imports

IP: Private investment
J: Operation rate of KP
KP: Capital stock

PCP: Deflator of CP

PE: Domestic oil price

PEX: Price index of export
PIM: Price index of import

PO: Crude oil price
POP: Population
RY: Exchange rate

SP: Output of service industry
T: Time trend

V: GDP
VO: Other component of GDP
W: Wages per worker
WIM: World import
WPI: Wholesale price index

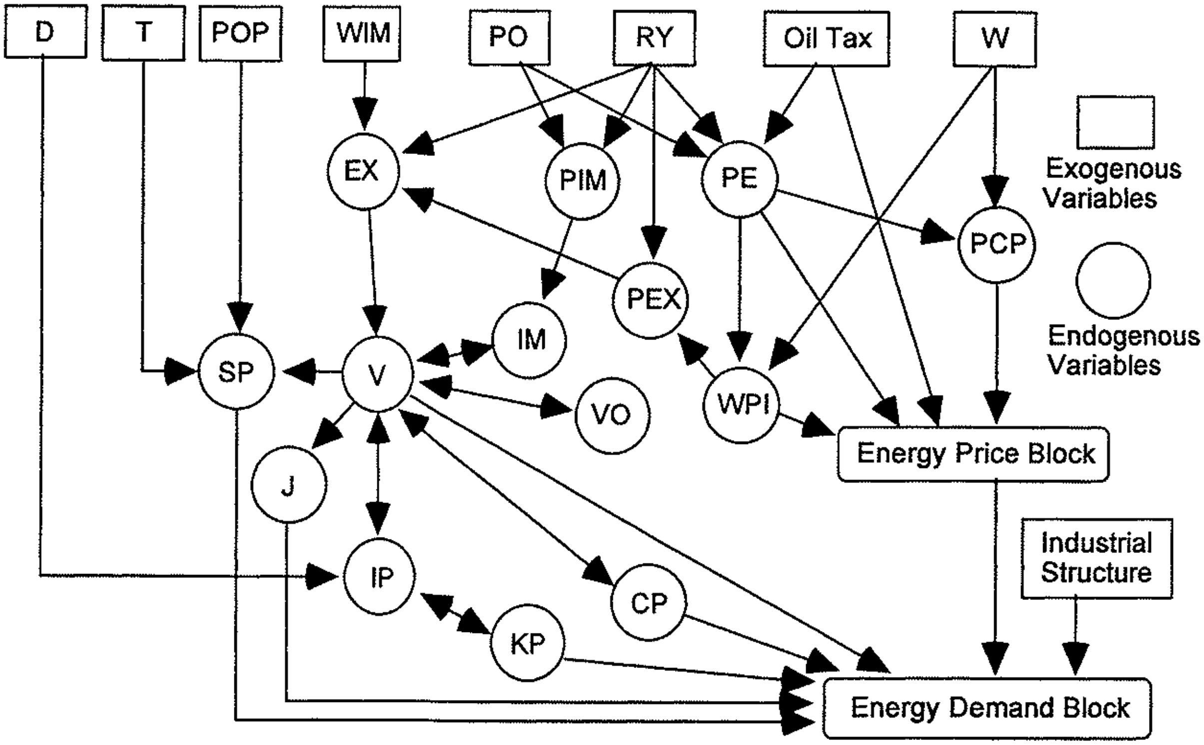

Fig. 2 Structure of Macro-Economy and Energy Model

5. Major Presupposition and Forecasted Results of Economic Variables

Table 2 shows the values of the major exogenous variables. The nominal price of crude oil is estimated from the Annual Energy Outlook 2000 (AEO2000) by the DOE/EIA (1999). Wages and industrial structures used are the forecasted values by CRIEPI (1998).

Table 2 Presupposition of Major Exogenous Variables

	1997	2000	2005	2010	Average Growth Rate 2010/1997 (%/year)
Crude Oil Price ($/bbl)	18.77	21.87	23.24	26.52	2.7
Exchange Rate (yen/$)	122.6	105.9	100.0	100.0	-1.6
Population (million)	126.2	126.9	127.7	127.6	0.1
Wages per Worker (thousand yen / person)	5,344	5,756	6,522	7,685	2.8
World Import (excluding Japan, billion $)	5,249	6,077	7,756	9,899	5.0
Share of Machinery Industry (%)	36.4	38.5	41.0	44.2	1.5
Share of Raw-Material Industry (%)	22.2	22.0	21.5	20.9	-0.5

Table 3 Annual Average Growth Rate of Final Energy Demand (1997-2010)

	Symmetric price elasticities (A)	Asymmetric price elasticities (B)	(B) – (A)
Final Demand Total	2.08%	2.33%	0.24%
Industrial Sector	1.84%	2.19%	0.35%
Electricity	2.10%	1.93%	-0.17%
Coal	1.75%	1.85%	0.10%
Petroleum	1.41%	1.77%	0.36%
Gas	4.86%	7.41%	2.55%
Commercial Sector	2.65%	3.30%	0.65%
Electricity	4.42%	4.50%	0.09%
Coal	2.54%	2.54%	0.00%
Petroleum	-0.07%	1.90%	1.97%
Gas	3.02%	3.12%	0.09%
Residential Sector	2.23%	2.08%	-0.15%
Electricity	2.94%	2.69%	-0.25%
Coal	-5.07%	-7.23%	-2.16%
Kerosene	1.49%	1.63%	0.14%
LPG	1.83%	1.46%	-0.37%
Gas	1.85%	1.72%	-0.13%
Transportation Sector	2.17%	2.37%	0.20%
Electricity	1.57%	1.67%	0.10%
Gasoline	2.03%	1.97%	-0.05%
Diesel Oil	2.81%	3.33%	0.52%
Heavy Oil	-0.69%	-0.49%	0.20%
LPG	0.54%	0.54%	0.00%
Jet Fuel	1.79%	1.79%	0.00%

Table 4 Comparison of GDP Elasticity between Past and Future

	Actual Record (1990-1997)	Forecasted Result (1997-2010)	GDP Elasticity	
			1997/1990	2010/1997
Real GDP	1.62%	2.09%		
Final Energy Demand	1.81%		1.12	
Symmetric Case		2.08%		1.00
Asymmetric Case		2.33%		1.12
Primary Energy Supply	1.99%		1.23	
Symmetric Case		2.24%		1.08
Asymmetric Case		2.38%		1.14

The forecasted results of energy demand are shown in Table 3 and Table 4. In most of the energy types, energy demand in the future with asymmetrical price elasticities is greater than that with symmetrical price elasticities. Figure 3 shows the schematic image of the reasoning behind this. In the asymmetrical case, maximum prices in the past (p_t^{max}) are most significant in more than half of the demand functions and p_t^{max} will not make a new record within the next ten or twenty years. This means that price effects will not work until future energy prices exceed the maximum levels of the past. The price elasticity of gas in the residential sector is not included in the symmetrical equations, and this is one of the reasons why gas demand in the residential sector is forecasted as smaller with the asymmetrical approach.

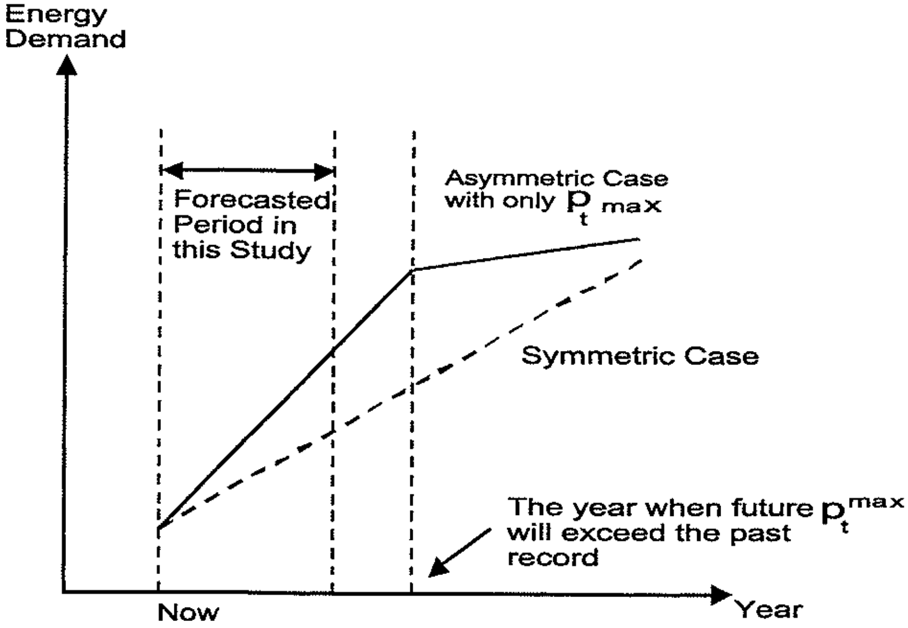

Fig. 3 Schematic Image of the Difference in Future Energy Demand

5. Conclusions and Discussion

We have estimated the energy demand functions of each sector and each type of energy in Japan with symmetrical and asymmetrical energy price elasticities. We have also forecasted future energy demand by using each demand function. The main results of this study are listed below:

- The asymmetrical approach shows better statistics of regression for price elasticities and the existence of asymmetry in price elasticities is confirmed. Among the decomposed energy prices using the asymmetrical approach, it is found that the elasticities for cumulative price cuts are insignificant in all of the functions and the maximum price in the past has the strongest effects on energy demand. This means that the absolute values of the elasticities for falling prices are smaller than those for rising prices and that the former are close to zero.
- We constructed a simple energy and economy model and combined it with demand functions, which have symmetrical and asymmetrical price elasticities respectively. Future energy demands up until 2010 are forecasted by using each model. By doing so, we found that the model with asymmetrical price elasticities overestimates the energy demand more than the model with symmetrical price elasticities, except in the residential sector.

Walker and Wirl (1993) have found that energy demand is overestimated if traditional demand functions are applied. Our findings indicate the opposite. We think this is because the choice of estimated period and method are different. They explained that an irreversible improvement in energy efficiency occurred in the period of rising prices before 1986 and the effects of that improvement remained even during the period of falling prices during 1986 to 1989. On the other hand, the data period we use is until 1997, and over ten years of the low energy price period are also included. This period is when the penetration of energy efficient technologies completed its first stage.

Another reason for the difference in findings is methodology. We have estimated the elasticities of the maximum price in the past, cumulative price increases and cuts. This resulted in the maximum price in the past showing the strongest effects. This means that energy prices do not work to decrease energy demand, unless future energy prices will make new record highs. In the forecasted results until 2010, most of the energy prices will not exceed the past peak; this explains why energy demand is forecasted as higher by the model with asymmetrical price elasticities.

One of the important implications of this study concerns controlling CO_2 emissions. It is often pointed out that price elasticities are small and therefore a high rate of carbon tax is needed to decrease CO_2 emissions. This study implies that the rate of carbon tax should be high enough for future energy prices to exceed the historical maximum levels. Because the model we have developed in this study does not incorporate the substitution between fuels, it is not suitable for the further quantitative analysis of the carbon tax. The implications of this study do not deny the applicability of econometric approaches to GHG analysis; however, it is important to recognize the characteristics and limits of the econometric approach. We plan to improve upon these points and will analyze them further in future studies.

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Appendix: Macro-Economy Block

1. $PE = PO*RY/0.159 + \text{Oil Tax}$

2. $WPI = \exp[0.958 + 0.209*\ln(W) + 0.196*\ln(PE)]$
(14.1) (19.6) (19.6)

1965-97, Adjusted $R^2 = 0.989$, Standard Error = 0.0307, D.W. = 1.08

3. $PEX = \exp[-0.212 + 0.716*\ln(WPI) + 0.334*\ln(RY)]$
(-1.17) (29.0) (20.4)

1965-97, Adjusted $R^2 = 0.963$, Standard Error = 0.0313, D.W. = 0.85

4. $PIM = \exp[0.903 + 0.500*\ln(PO*RY)]$
(12.2) (52.5)

1965-97, Adjusted $R^2 = 0.989$, Standard Error = 0.445, D.W. = 1.09

5. $PCP = \exp[-0.236 + 0.228*\ln(W) + 0.0244*\ln(PE) + 0.582*\ln(PCP_{-1})]$
(-5.23) (9.80) (5.30) (16.6)

1965-97, Adjusted $R^2 = 0.999$, Standard Error = 0.0141, D.W. = 2.08, Durbin's h = 1.53

6. $VO = \exp[0.967 + 0.218*\ln(V) + 0.671*\ln(VO_{-1})]$
(5.16) (2.68) (7.11)

1965-97, Adjusted $R^2 = 0.990$, Standard Error = 0.0336, D.W. = 1.46, Durbin's h = 1.64

7. $CP = \exp[0.262 + 0.558*\ln(V) + 0.397*\ln(CP_{-1})]$
(3.73) (8.11) (5.83)

1965-97, Adjusted $R^2 = 0.999$, Standard Error = 0.989E-02, D.W. = 1.23, Durbin's h = 2.35

8. $IP = 2841.1 + 0.0747*V + 0.0474*KP_{-1} + 14726.3*D$
(0.52) (1.97) (3.13) (5.95)

1966-97, Adjusted $R^2 = 0.972$, Standard Error = 3919.65, D.W. = 0.987

9. $EX = \exp[3.154 + 0.253*\ln(WIM) - 0.681*\ln(((PEX/WIM*RY) + (PEX/WIM*RY)_{-1})/2)]$
(3.91) (1.90) (-2.99)

1966-97, Adjusted $R^2 = 0.980$, Standard Error = 0.0952, D.W. = 0.423

10. $IM = \exp[-2.335 + 0.544*\ln(V) - 0.146*\ln(PIM_{-1}) + 0.626*\ln(IM_{-1})]$
(-3.50) (4.65) (-5.48) (7.82)

1965-97, Adjusted $R^2 = 0.991283$, Standard Error = 0.0520, D.W. = 1.67, Durbin's h = 0.930

11. $V = CP + IP + EX - IM + VO$

12. $KP = -319.6 + 0.956*IP + 0.959*KP_{-1}$
(-0.11) (6.91) (81.5)

1969-97, Adjusted $R^2 = 1.000$, Standard Error = 5064.66, D.W. = 2.29, Durbin's h = -0.806

13. $J = 48.77 + 136.4*(V-V_{-1})/V_{-1} + 0.491*J_{-1}$
(5.20) (5.20) (5.41)

1969-97, Adjusted $R^2 = 0.788$, Standard Error = 3.331, D.W. = 1.78, Durbin's h = 0.462

- Figures in parentheses denote t-statistics of coefficients.
- Subscript –1 means one year before