

Estimation of Price Elasticity of Energy Demand in Japan Considering Socio-economic Structure Changes

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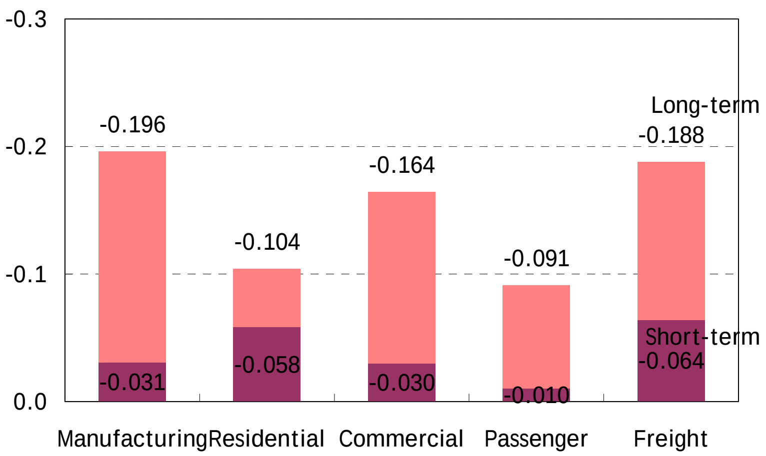
Summary

How much are the effects on energy consumption or carbon dioxide emissions of changes in energy prices and taxation system? Price elasticity is one of the answers given for such frequently asked question both simply and quantitatively.

Price elasticity is often used in analysis as it is easy and its application ranges widely. Nonetheless, there is no price elasticity, which is accepted extensively. It, however, is generally accepted that energy consumption is rather price–inelastic. The inelasticity comes from characteristics of energy as a necessity.

We have to pay attention to slow but continuous changes in macro energy system. In some cases, the changes cannot be distinguished from other socio–economic structure changes easily. Nevertheless, the effect of such continuous structure changes will be confined to price elasticity if we perform regression analysis of energy consumption ignoring such structure changes completely. Consequently, more elastic price elasticity tends to be concluded than true value. We illustrate a practical method to estimate price elasticity considering continuous structure changes.

Price elasticity by sector



The estimated short– and long–term price elasticity were around -0.01 to -0.06 and -0.1 to -0.2, respectively, reinforcing the common perception that energy is rather price–inelastic. As price elasticity is easy to handle, further scrutiny is needed when it is estimated.

Keywords: price elasticity, structure change, energy consumption

Introduction

"How is energy consumption affected by increases in oil prices?"

"To what extent carbon dioxide emissions will be reduced by carbon tax?"

Price elasticity — the percentage change in energy consumption against a change in energy price of one percent — is one of the answers given for such frequently asked questions both simply and quantitatively.

Once price elasticity is obtained, analysis using it is easy and it has a wide range of applications. Therefore, price elasticity is often analysed and a number of studies have actually measured price elasticity. Nonetheless, there is no price elasticity, which is generally accepted. One of the reasons is that the observed price elasticity differs much in some cases due to differences in boundary of analysed energy consumption and period, kinds of prices, included factors other than energy prices and differences in statistical estimators.

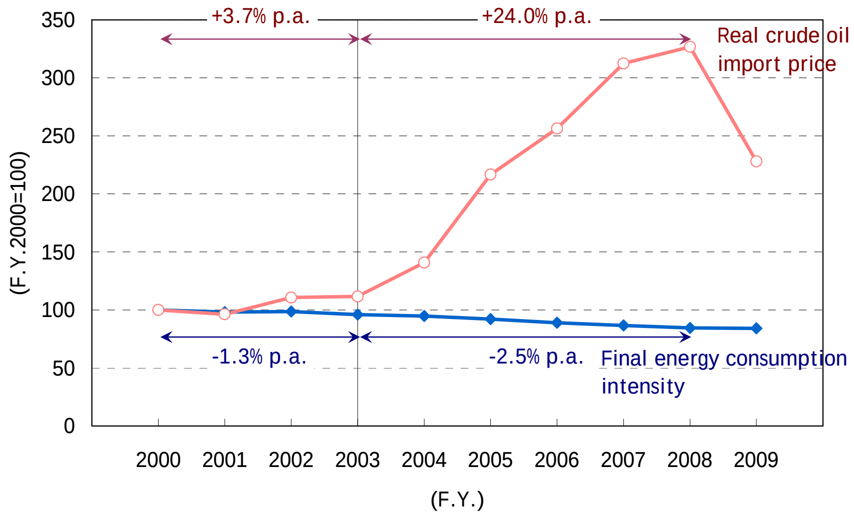
It, however, is generally accepted among energy analysts that energy consumption is rather price–inelastic. The inelasticity of energy comes from facts that energy has a characteristic of necessities, as its demand is not easily replaced due to energy equipments like boilers, vehicles, electric appliances, etc. are barely replaced with new ones due to their long lifetime. The situation in the 2004 to 2008 period, in which crude oil prices skyrocketed more than twice[1], can be listed as one of recent instances that show energy consumption is insensitive against changes in energy prices. Although improvement of energy efficiency (final energy consumption intensity per real GDP) in the period accelerated from the previous period when the prices were stable, the change was considerably small compared with changes in the prices (Figure 1).

Nevertheless, some studies show rather elastic price elasticity. In some cases, the estimation period might be very long that breaks in socio–economic structure affect estimation results considerably. In other cases, the number of samples might be too small due to short estimation period, which make estimation inaccurate — as often pointed out in econometric analyses. The issues are classical but troublesome.

Additionally we have to pay attention to the characteristics of energy as shown above when we estimate price elasticity of energy. Macro energy system changes slowly but continuously. In some cases of analyses, the changes cannot be distinguished from other socio–economic structure changes easily. Nevertheless, the effect of such continuous structure changes will be confined to price elasticity (and income elasticity) if we perform regression analysis on energy consumption only with price (and income), ignoring completely those structure changes. Consequently, people tend to conclude price elasticity is more elastic than true value.

[1] In terms of real Japanese Yen. The rise was more than triple in term of nominal dollar.

Figure 1 Real crude oil price and energy efficiency in Japan



Source: The Institute of Energy Economics, Japan (IEEJ) "EDMC Handbook of Energy & Economic Statistics in Japan"

This paper focuses on continuous structure change. We illustrate a practical method to estimate price elasticity that considers structure changes.

Estimation of price elasticity considering continuous structure changes

Handling structure changes

The most common way to express continuous structure changes in regression analyses is adding a time trend term in independent variables[2]. Time trend works well as proxy of structure changes if those changes are monotonous. In some cases, non–liner time trend is included.

Energy is consumed through energy equipments that have long lifetimes and the stocks are replaced gradually in a macro point of view. Therefore, without unusual installation of high efficiency equipments due to rises in energy prices, it could be expected that average energy efficiency improves in some degree every year by regular replacement of existing stocks. Excluding time trend from independent variables in estimating price elasticity leads to confine energy saving effect, which is brought by improvement of average efficiency by routine replacement of stocks, in the price factor. That often causes obtaining more elastic price elasticity than the actual one in regression analyses (see Annex).

It is favourable that we estimate price elasticity distinguishing effects brought about by structure changes, which affect energy consumption. Those principal drivers are not

[2] For structure changes in a certain period or point, 0–1 type dummy variable is used.

energy prices, such as mentioned above but improvement in stock efficiency. One way is to limit sectors and areas and minimise range of energy consumption to be analysed. Subdivision, however, leads to deterioration in availability and quality of data and often results in less accurate analyses.

Considering above, this paper adopted the following method:

1/ Quantifying a "reference" value, an imaginary energy consumption which includes continuous structure change factors, and

2/ Estimating price elasticity using ratio of actual energy consumption to the reference.

This practical method enables to avoid infiltration of structure change factors into price elasticity.

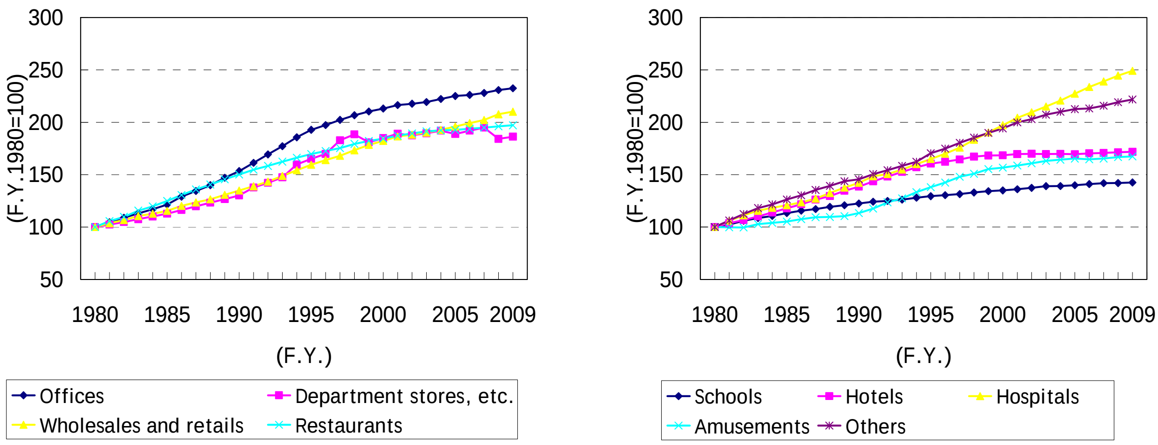
We show concrete explanation of the method with an example of estimation of price elasticity in the commercial sector, followed by other sectors in Japan.

Price elasticity of the commercial sector

The commercial sector consists with various subsectors such as offices (including headquarters of manufacturing industries), shops, services establishments, schools, etc. They are often small energy consumers. Therefore, energy statistics of the commercial sector is not compiled as well as that of the manufacturing sector.

Although they are categorised in the commercial sector, the subsectors vary a lot. For example, energy intensity per floor space of restaurants is more than five times higher than that of schools. At the same time, growth rates of subsectors' floor space vary a lot reflecting socio–economic situation although commercial floor space shows increasing trend in total (Figure 2). Therefore, estimation of price elasticity by subsector is favourable if possible. Unfortunately, it is impossible in Japan, as not enough statistics has been compiled yet.

Figure 2 Floor space for commercial use



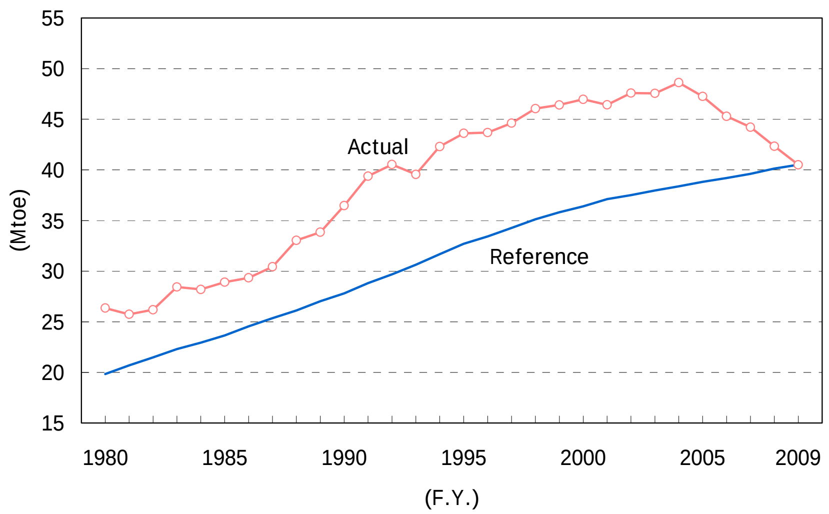
Source: IEEJ "EDMC Handbook of Energy & Economic Statistics in Japan"

In this paper, price elasticity of the commercial sector was estimated as a whole but treating structure change explicitly stemming from the different growth by the subsectors. Reference energy consumption was quantified with energy intensity (energy consumption per floor space; cal/m²) of each subsector in base year (F.Y. 2009) and activity level (floor space; m²) of each subsector in each year.

$$\text{Reference energy consumption}_t = \sum_i \text{Energy intensity of subsector } i_{\text{base year}} \times \text{Activity level of subsector } i_t . \quad (1)$$

Changes in the reference value are caused by structure changes — by only changes in the activity level in each subsector.

Figure 3 Energy consumption in the commercial sector (actual and reference values)



Source: IEEJ "EDMC Handbook of Energy & Economic Statistics in Japan" (actual value)

The ratio of the actual energy consumption of the sector to the reference includes no structure change factor caused by differences in the growth of the subsectors. Regression analysis with the ratio as a dependent variable allows us to estimate the price elasticity without the influence of the structure change factor. A basic formula of the estimation model is as follows:

$$\log \frac{\text{Actucal energy consumption}_t}{\text{Reference energy consumption}_t} = \beta_C + \beta_P \log \text{Price}_t + u_t . \quad (2)$$

In the estimation, independent variables included the following: (i) real average energy prices in the commercial sector deflated by GDP deflator, (ii) real GDP per capita, (iii) time trend for other continuous structure changes not expressed by the reference value such as the average efficiency improvement by replacement of stocks, (iv) percent changes in heating and cooling degree–days, which express heating and cooling load, compared with the previous year, and (v) a Koyck lag[3] for distinguishing between short–term price elasticity and long–term price elasticity. The estimation period was F.Y. 1980 to F.Y. 2009 (the same shall apply hereinafter).

The estimation results are shown in Table 1. For comparison, results of traditional estimation in intensity method using energy consumption per GDP as a dependent variable and the same independent variables other than replacing real GDP per capita with real GDP amount are shown also.

Table 1 Price elasticity of the commercial sector

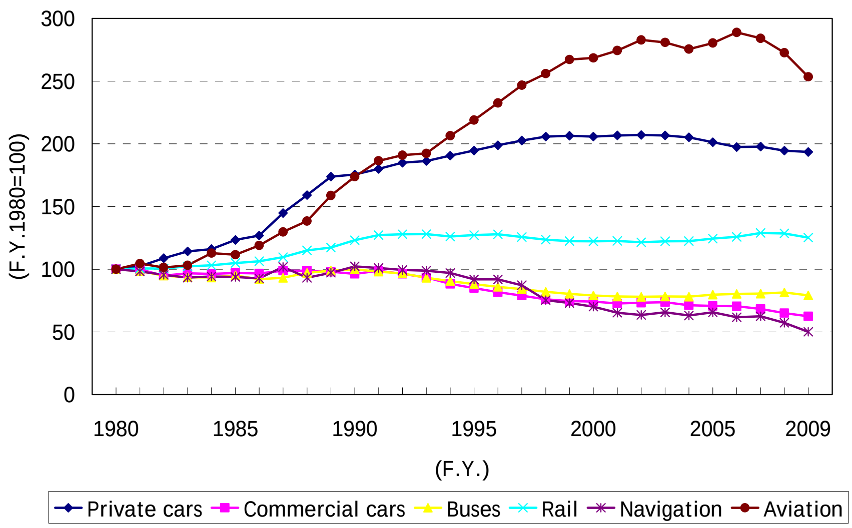
	Short–term	Long–term
Reference method	-0.030	-0.164
(Memo.) Intensity method	-0.024	-0.300

Differences in the growth of the subsectors markedly affect the estimation of price elasticity in the sector — especially long–term elasticity. Unless, considering the differences, long–term price elasticity will be concluded to be about twice elastic.

Price elasticity of the passenger sector

The passenger sector covers energy consumption for human mobility[4]. Private cars, which are energy inefficient compared with public transportation, accounted for 84% of energy consumption in the sector in F.Y. 2009.

Figure 4 Passenger travelled (passenger-kilometres)



Source: IEEJ "EDMC Handbook of Energy & Economic Statistics in Japan"

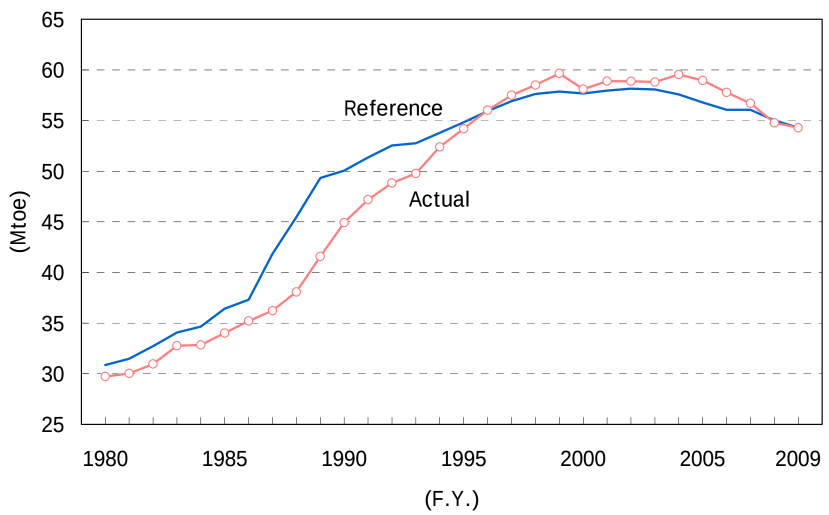
[3] Value of dependent variable in the previous period.
[4] Includes energy consumption by private cars.

Although energy prices seem to play a role as one of factors in choosing transport modes for mobility, especially for choices of private cars, they are not the primary determinants. Availability of alternative modes, differences in transport time, changes in business mobility demand related to economic trend and total costs including highway toll, taxes on vehicles, etc. are greater factors than energy prices for choices in modes and total mobility demand.

We estimated price elasticity of the passenger sector treating explicitly a structure change factor stemming from the differences in passenger travelled by mode. Reference energy consumption was quantified with energy intensity (energy consumption per passenger–kilometre, or pkm; cal/pkm) of each mode in F.Y. 2009 and passenger travelled (pkm) by each mode in each year.

$$\text{Reference energy consumption}_t = \sum_i \text{Energy intensity of mode } i_{\text{base year}} \times \text{Passenger travelled by mode } i_t. \quad (3)$$

Figure 5 Energy consumption in the passenger sector (actual and reference values)



Source: IEEJ "EDMC Handbook of Energy & Economic Statistics in Japan" (actual value)

Price elasticity was estimated by using the ratio of actual energy consumption of the passenger sector to the reference as a dependent variable. Real average price in the sector deflated by GDP deflator, real GDP per capita, time trend and a Koyck lag were used as independent variables. The results are shown in Table 2. For comparison, results of traditional estimation in intensity method using energy consumption per GDP as a dependent variable and the same independent variables except for replacing real GDP per capita with real GDP amount are shown also.

Table 2 Price elasticity of the passenger sector

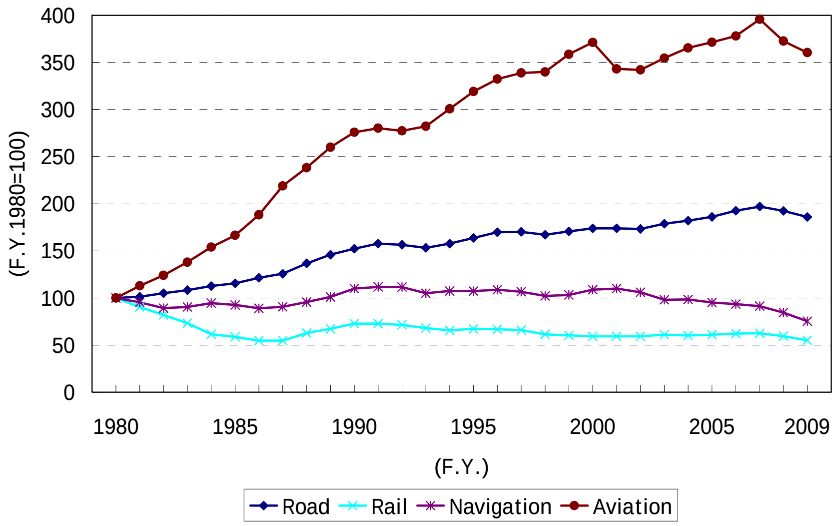
	Short–term	Long–term
Reference method	-0.010	-0.091
(Memo.) Intensity method	-0.110	-0.554

Although the intensity method gives rather elastic long–term price elasticity, the elasticity reduces less than one sixth once the structure change factor is eliminated. In the intensity method, price elasticity results in similar values irrespective of usage of time trend, suggesting that the influence of the structure change factor cannot be prevented by only time trend.

Price elasticity of the freight sector

While the passenger sector covers energy for human mobility, the freight sector involves energy use for transport of goods. Road accounted for 86% of energy consumption in the freight sector in F.Y. 2009, a little less than in the passenger sector.

Figure 6 Freight travelled (tonne-kilometres)



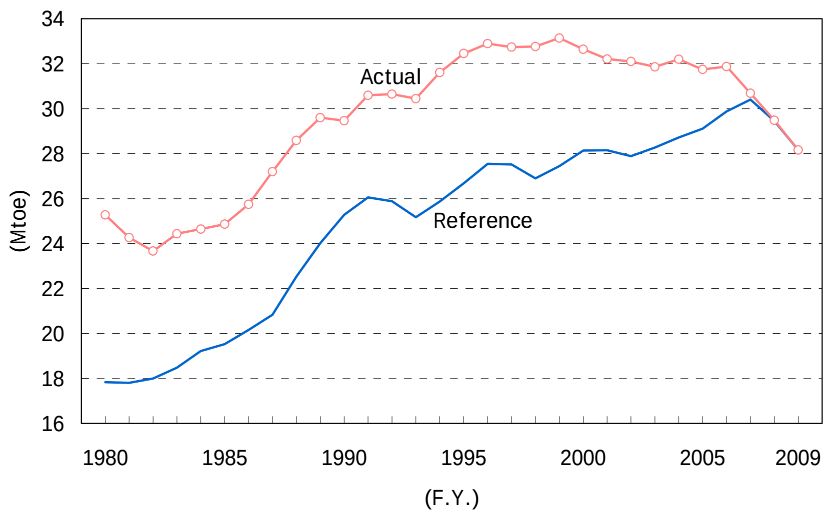
Source: IEEJ "EDMC Handbook of Energy & Economic Statistics in Japan"

Although energy prices also affect which modes is chosen for transport of goods, they are not the principal determinants as in the passenger transport. In choices of modes, kinds of goods to be transported, needs for transport services — speed, mobility, frequency, etc. — and delivery points are more important factors.

We estimated price elasticity of the freight sector by treating explicitly a structure change factor stemming from differences in freight travelled by mode as we did for the passenger sector. Reference energy consumption was quantified with energy intensity (energy consumption per tonne–kilometre, or tkm; cal/tkm) of each mode in F.Y. 2009 and freight travelled (tkm) by each mode in each year.

$$\text{Reference energy consumption}_t = \sum_i \text{Energy intensity of mode } i_{\text{base year}} \times \text{Freight travelled by mode } i_t . \quad (4)$$

Figure 7 Energy consumption in the freight sector (actual and reference values)



Source: IEEJ "EDMC Handbook of Energy & Economic Statistics in Japan" (actual value)

Price elasticity was estimated by using the ratio of actual energy consumption of the freight sector to the reference as a dependent variable. Real average price in the sector deflated by GDP deflator, index of industrial production, or IIP per capita, time trend and a Koyck lag were used as independent variables. The results are shown in Table 3. For comparison, results of traditional estimation in intensity method using energy consumption per GDP as a dependent variable and the same independent variables except for replacing IIP per capita with IIP are shown also.

Table 3 Price elasticity of the freight sector

	Short–term	Long–term
Reference method	-0.064	-0.188
(Memo.) Intensity method	-0.128	-0.237

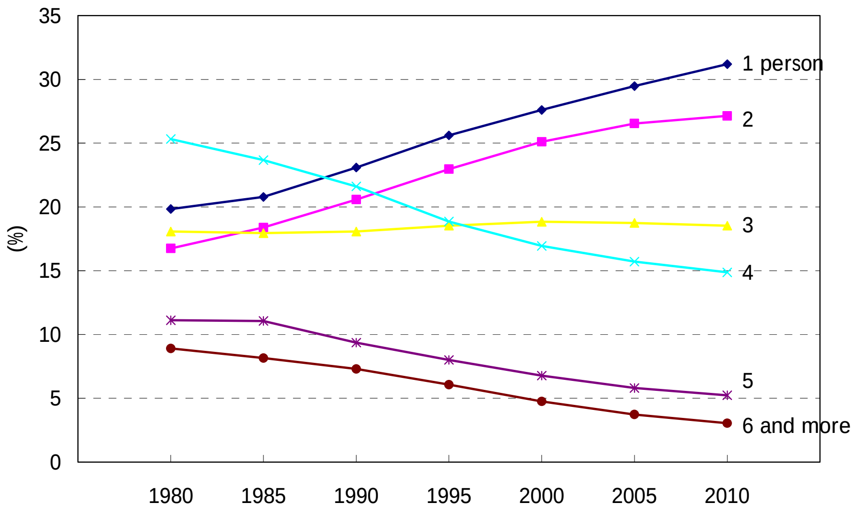
The price elasticity of the sector becomes inelastic by treating the structure change factor explicitly. The percentage changes are not negligible but the changes in level are small. The results imply a little possibility that price elasticity of the sector is affected by the structure change factor.

Price elasticity of the residential sector

Energy consumption in the residential sector is determined by energy intensity per household, which is characterised by regionality stemming from difference in space heating load, and population per household. Correlation relationship exists between population and energy consumption per household. The intensity, however, does not reduce to half even if population per household halves. Increase of small–sized households contributes to growth in total energy consumption in the residential sector.

In the last three decades, Japan has seen almost no change in household mix by region. Household mix by population, by contrast, has shown clear trend that large–sized households have declined and single and two–person households combined have increased to more than half (Figure 8).

Figure 8 Household mix by population

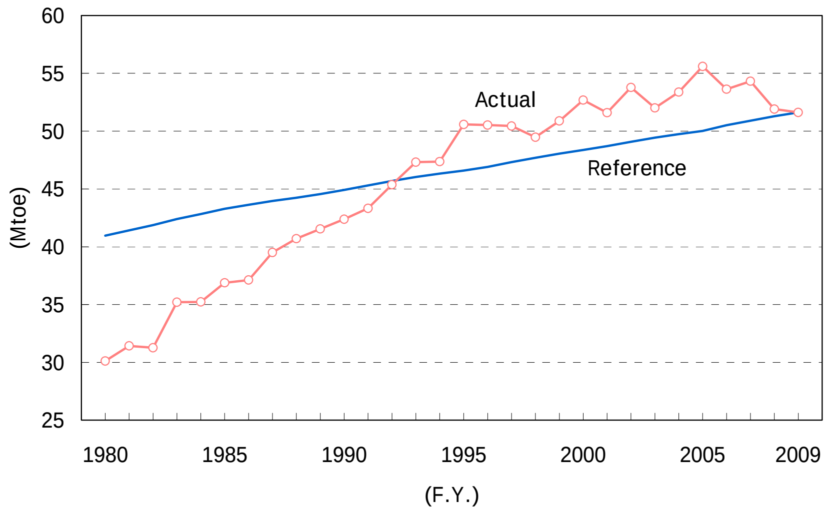


Notes: Private households. Preliminary sample results for 2010.
Source: Statistical Bureau "Population Census"

We estimated price elasticity of the residential sector by treating explicitly a structure change factor in household mix by population. Reference energy consumption was quantified with energy intensity (energy consumption per household; cal/household) of each size of household in F.Y. 2009 and number of households by population in each year.

$$\text{Reference energy consumption}_t = \sum_i \text{Energy intensity of household size of } i_{\text{base year}} \times \text{Number of household size of } i_t . \quad (5)$$

Figure 9 Energy consumption in the residential sector (actual and reference values)



Source: IEEJ "EDMC Handbook of Energy & Economic Statistics in Japan" (actual value)

Price elasticity was estimated by using the ratio of actual energy consumption of the residential sector to the reference as a dependent variable. The estimation was conducted by end–use — space heating, space cooling, water heating, cooking, and lighting and power. Real average price in the sector deflated by consumer price index, real private consumption expenditure per household, time trend and a Koyck lag were used as independent variables. As (water) temperature factor, heating degree–days, cooling degree–days and both of them were also used in form of percentage change from the previous year for estimation of space heating, space cooling and water heating, respectively. In addition, a dummy variable for 2007 and 2008, when the electricity–saving movements after the Niigataken Chuetsu–oki Earthquake seemed effective, was applied for estimation of space cooling. For comparison, results of traditional estimation in intensity method using energy consumption per household as a dependent variable and the same independent variables are shown also.

Only for space heating and water heating, economically rational — negative — price elasticity was obtained irrespective of the estimation method. Price elasticity of the residential sector was obtained by weighted average of price elasticity with energy consumption in F.Y. 2009 by use, regarding irrational — positive — price elasticity as zero.

As a result, there was no big difference between the reference method and the intensity method, suggesting the structure change in the sector is monotonous and time trend can be proxy for it.

Table 4 Price elasticity of the residential sector

	Short–term	Long–term
Reference method	-0.058	-0.104
Space heating	-0.136	-0.309
Space cooling	n.a.	n.a.
Water heating	-0.128	-0.165
Cooking	n.a.	n.a.
Power and lighting	n.a.	n.a.
(Memo.) Intensity method	-0.055	-0.100
Space heating	-0.135	-0.304
Space cooling	n.a.	n.a.
Water heating	-0.114	-0.149
Cooking	n.a.	n.a.
Power and lighting	n.a.	n.a.

Price elasticity of the manufacturing

The industry sector includes direct energy use for production of goods[5], consisting of manufacturing, agriculture, forestry, fishery and mining[6]. Manufacturing is a dominant subsector, accounting for 94% of energy consumption in the industry sector in F.Y. 2009.

Activity trend differs by subsector in the sector similar with the commercial sector. While textile and cement have production have gone down, machinery and ethylene almost doubled their production in the last three decades. In terms of energy, energy consumption per production is much different from energy intensive basic material manufacturing — iron and steel, chemicals, non–metallic minerals and paper and pulp — and non–basic material manufacturing — food, textile, non–ferrous metals, metals and machinery, and others.

Rises in energy prices are unfavourable especially for the basic material manufacturing as they have high share of energy in total production costs. Energy *prices*, however, are just small factors, which influence industry structure with the exception of primary aluminium refining after the oil crises due to the climb of electricity price. For instance, the increasing worry about the transfer of manufacturing industries abroad after the Great East Japan Earthquake is much associated with the appreciation of the Japanese Yen, labour cost, taxes and *secure supply* of energy, etc.

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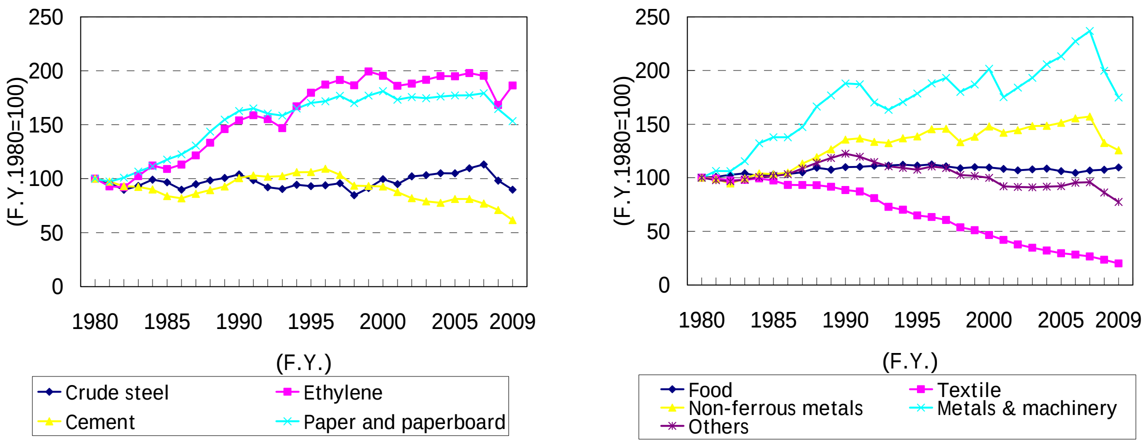
[5] Energy consumption in back offices and that for transport of produced goods and materials are included in the commercial sector and the freight sector, respectively. Whilst fuel input for auto-generation of electricity is recorded in the power generation sector, consumed auto-generated electricity is recorded in the industry sector.

[6] Agriculture, forestry and fishery are not in industry sector but they compose "Other" sector with buildings in energy balance tables of the International Energy Agency.

Figure 10 Production level in the manufacturing

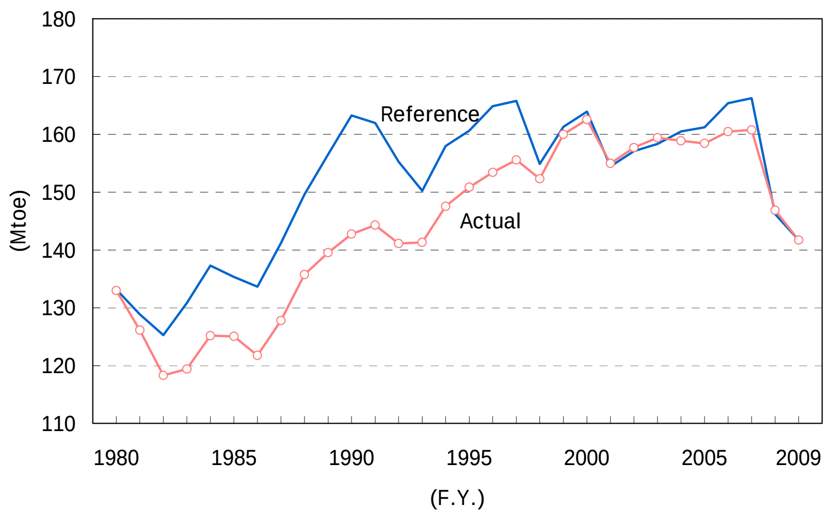


Notes: Production amount (tonne) for basic materials (left); Indices of production for non–basic materials (right).
Source: IEEJ "EDMC Handbook of Energy & Economic Statistics in Japan"

We estimated the price elasticity of the manufacturing subsector treating explicitly a structure change factor stemming from differences in activity level by subsector. Reference energy consumption was quantified with energy intensity of each subsector in F.Y. 2009 and activity level (tonne for the basic materials and indices of production for the non–basic materials manufacturing) by each subsector in each year.

$$\text{Reference energy consumption}_t = \sum_i \text{Energy intensity of subsector } i_{\text{base year}} \times \text{Activity level of subsector } i_t . \quad (6)$$

Figure 11 Energy consumption in the manufacturing (actual and reference values)



Source: IEEJ "EDMC Handbook of Energy & Economic Statistics in Japan" (actual value)

Price elasticity was estimated by using the ratio of actual energy consumption of the manufacturing to the reference as a dependent variable. Real average price in the manufacturing subsector deflated by domestic corporate goods price index, percentage change of index of manufacturing production compared with the previous year, time trend and a Koyck lag were used as independent variables. The results are shown in Table 5. For comparison, results of traditional estimation in intensity method using energy consumption per index of manufacturing production as a dependent variable and the same independent variables are shown also.

Table 5 Price elasticity of the manufacturing

	Short–term	Long–term
Reference method	-0.031	-0.196
(Memo.) Intensity method	-0.098	-0.580

By treating the structure change factor explicitly, both short–term price elasticity and long–term price elasticity became more inelastic by two–thirds. The effect brought by differences in the growth by the subsector (or structure change) on price elasticity estimation is not to be disregarded; otherwise, we might conclude that price elasticity is rather elastic.

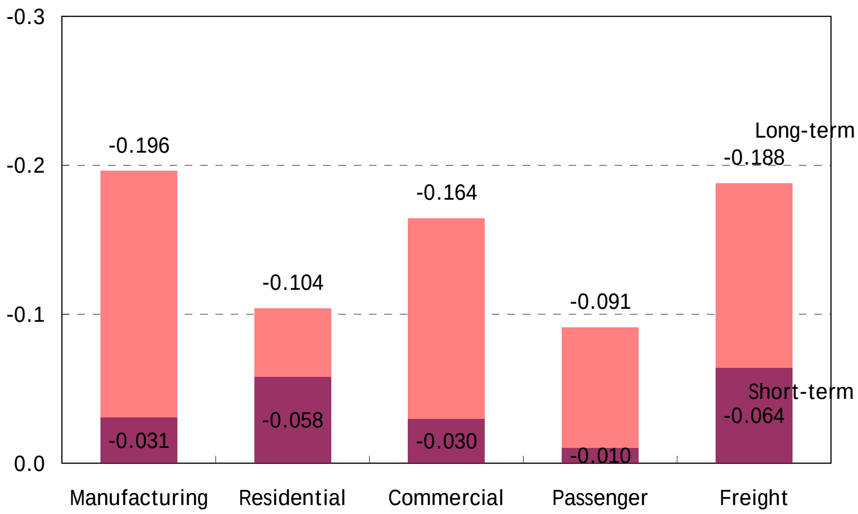
In closing

Additionally, the required energy consumption data by subsector (by mode, by population per household) are only those in the base year in the method used in this paper. If we estimate price elasticity by each subsector to avoid the influence of structure change factors, time series energy consumption data by subsector are needed. It is not easy thing depending on sector. Strictly speaking, not only energy consumption data but also price data by subsector are required — *e.g.* electricity prices of restaurants may be different from that of hotels. It, however, is not an easy matter. It is nonsensical to seek excess rigidity at the expense of possibility and/or accuracy of analysis, especially when we focus on price elasticity because analyses using it are no more than expedient.

The estimation considering continuous structural changes resulted in around -0.01 to -0.06 of short–term price elasticity and around -0.1 to -0.2 of long–term price elasticity in major final energy consumption sectors in Japan. They are in line with our other estimation results of price elasticity of gasoline (Yanagisawa, 2008; Yanagisawa, 2010), reinforcing the common idea that energy consumption is rather inelastic against price.

Analysis using more elastic price elasticity than the actual one may lead to misleading conclusion, *e.g.* overestimating effect by carbon tax. As price elasticity is easy to handle, scrutinising is needed when it is estimated.

Figure 12 Price elasticity by sector



Annex: Effect of time trend

Consider a following log–linear model estimating price elasticity. For simplification, all of the variables are assumed to be transformed in deviation from their averages.

$$d = \beta_Y y + \beta_P p + \beta_T t + u \qquad (7)$$

where d is energy demand in logarithm, y is activity in logarithm, p is price in logarithm, t is time trend, u is an error term. β_Y and β_P correspond to income elasticity and price elasticity, respectively. $\hat{\beta}_Y$ and $\hat{\beta}_P$ are estimation of those by ordinary least squares.

When time trend is not included in independent variables, the model is

$$d = \beta_Y y + \beta_P p + v. \qquad (8)$$

We consider a relationship between $\hat{\beta}_P^*$, estimation of β_P in equation (8), and $\hat{\beta}_P$.

$\hat{\beta}_P^*$ can be understood as estimation of β_P in equation (7) subject to $\beta_T = 0$. Letting income and price uncorrelated as an ideal case in regression analysis, the relationship between $\hat{\beta}_P^*$ and $\hat{\beta}_P$ is

$$\hat{\beta}_P^* = \hat{\beta}_P + \frac{\sum pt}{\sum p^2}\hat{\beta}_T. \qquad (9)$$

$\hat{\beta}_P^*$ is expected to be negative as it is the price elasticity. $\sum pt$ and $\hat{\beta}_T$ may be positive and negative, respectively, in many cases due to rises in real energy price by time and gradual improvement of energy efficiency. Then $\hat{\beta}_P^*$ is less than $\hat{\beta}_P$ (absolute value of $\hat{\beta}_P^*$ is larger than that of $\hat{\beta}_P$), meaning we tend to have more elastic price elasticity when we exclude the time trend from independent variables.

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