

Quantifying the risk of an increase in the prices of non-energy products by
combining the portfolio and input-output approaches

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Abstract

An increase in the price of imported fossil fuels indirectly increases the producer price in non-energy sectors; however, this indirect influence cannot be taken into account by the traditional portfolio approach. This study proposes an analytical framework combining the input-output (I-O) model and the portfolio approach that can take the indirect influence into account. A risk of an increase in the producer price in Japanese non-energy sectors

during the period 1970–2000 is estimated, and the causes of a decrease in the risk through the analysis period are clarified by decomposing an index of the risk. The result indicates that almost all non-energy sectors have decreased this risk during the analysis period. The degree and cause of the decrease depends on a sector's location in the hierarchical structure of Japanese industries. For example, assembly sectors have decreased their risk mainly as the result of improvement in energy usage by upstream sectors, such as material sectors, rather than their own improvements. Proper policies considering such a structure are required to decrease the risk further because the effort taken to do so is seldom motivated by economic profit.

Keywords: Leontief price model, portfolio approach, decomposition analysis

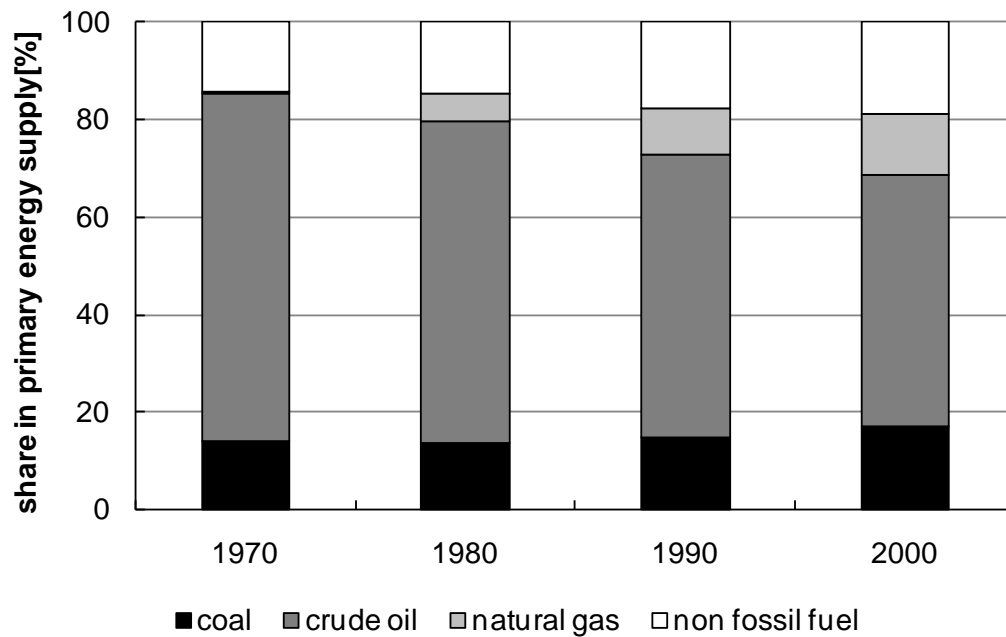


Figure1. Share of imported fossil fuels in the primary energy supply in Japan.

Source: IEEJ (2007)

1. Introduction

The producer prices of Japanese industrial sectors can be increased by increasing the prices of imported fossil fuels, because Japan has been heavily reliant on imported fossil fuels to cover its energy demand, as depicted in Figure 1. The price crisis of fossil fuels can affect the non-energy sectors—that is, industrial sectors producing non-energy goods or services—as well as energy conversion sectors. For example, the Japanese chemical, steel, and metal products sectors increased their producer prices

1.9, 1.7, and 1.8 fold, respectively, during the terms of the two oil crises (Bank of Japan website). There are two types of influence from the prices of fossil fuels to the prices of non-energy products: direct influence arising from the consumption of energy products, and indirect influence arising from the consumption of non-energy products. Both influence need to be clarified for mitigating the impact of an uncertain increase in the price of imported fossil fuels on an economy, especially the impact of an extreme price increase.

To quantify both the direct and indirect influence, the overall structure of the industry needs to be considered because the amount of indirect influence is determined by the structure of various production chains. The Leontief price model (Leontief, 1966; Miller and Blair, 1985), a method based on the input-output (I-O) model, has been applied for this purpose. Hattori and Matsue (2006) estimated the rate of increase in the producer price of industrial sectors of Japan during three periods: the first and second oil crises, and the Iraq war. Their results indicate that the rate of increase in all sectors during the Iraq war was lower than that in the two other periods. Fujikawa et al. (2007) estimated a crude oil price elasticity of the domestic price in Japan, and showed that the elasticity largely decreased in the 1970s

and 1980s¹. However, these studies did not consider uncertainty in the price of fossil fuels, for example, the frequency of extreme price increases.

On the other hand, the portfolio approach (Markowitz, 1952) was applied to estimate the risk of an increase in the producer price of the energy conversion sectors, taking into account the uncertainty in the price of fossil fuels. Lesbirel (2004) showed that changes in the fossil fuel mix in Japan decreased the risk of increase in the supply cost of fossil fuels since 1970. Hattori (2007) showed that the primary energy mix of the electric utility sector in Japan minimized the risk of increase in the cost for energy supply to some extent. Suzuki and Uchiyama (2009) analyzed the relationship between changes in the fossil fuel mix and the risk of increase in the supply cost for the electric utility sector in Japan, and showed that this sector has attempted to decrease the risk by substituting crude oil with coal and natural gas². However, the existing portfolio approach can quantify only the direct influence of an increase in the price of fossil fuels because it cannot take the overall structure of the industry into account.

Lian et al. (2007) and Santos (2008) proposed a method to provide probabilistic input to the I-O model for a risk analysis of large-scale

infrastructure and economic systems. The purpose of this method is to estimate the total economic loss caused by risk events, such as malicious attacks or natural disasters. The output of this model is given as a probabilistic distribution because the inputs of the model, demand perturbation caused by risk events, are also given as a probabilistic distribution. The conditional value at risk³, defined as an expected value in only the upper tail of the probabilistic density function for the damage, is applied as the risk index.

This study proposes an analytical framework combining the I-O model and the portfolio approach, based on the concept of a probabilistic I-O model, and estimates the risk of increase in the producer price in non-energy sectors. Both the overall structure of the industry and the uncertainty in the price of fossil fuels are considered. The portfolio approach estimates the risk from three factors: the risk of increase in the price of each fossil fuel, the correlations among prices of fossil fuels, and the share of each fossil fuel (Costello, 2005). This study develops the method using the I-O table instead of the share of each fossil fuel, and estimates a risk of increase in the producer price of Japanese non-energy sectors during the period

1970–2000. The conditional value at risk (CVaR) is adopted as an index of the risk because this index is suitable for representing harm or losses from extreme events. The causes of risk reduction through the analysis period are clarified by decomposing the risk index into constituent parts of direct and indirect inputs of fossil fuels and final energies. In addition, the relationship among the change in the CVaR, the energy cost per unit production, and the rate of added value are analyzed. Some implications are derived from the results of these analyses.

2. Methodology

2.1. Increase in the producer prices in non-energy sectors

2.1.1. Estimating an increase in the producer prices

The Leontief price model estimates the change in the rate of the producer prices in industrial sectors caused by an exogenous change in the price of production factors. Note that the estimated price calculated by this

model is a shadow price that considers only the costs of materials and production factors. Producer prices in each sector in an equilibrium condition can be represented as

$$P = A^t P + V, \quad (1)$$

where P indicates the producer price in each sector, A indicates the input coefficients, i.e., the cost of one sector as a payment per unit production to another sector, and V indicates a payment per unit production to the production factors (Miller and Blair, 1985).

In this study, we make two modifications to equation (1): externalizing fossil fuel sectors which produce primary fossil fuel energies, and distinguishing domestic and imported products from each other.

First, three fossil fuel sectors, i.e., coal, crude oil, and natural gas sectors, are externalized to focus on the influence of increase in the price of fossil fuels on the price of products other than fossil fuels. In other words, fossil fuel sectors are assumed not to obtain any inputs from other sectors. This externalization seldom influences on analytical results because inputs to the three fossil fuel sectors cover only 0.1% of the total production in Japan though the analysis period (Kawashima, 2005). For the externalization, P , V ,

and A are decomposed as

$$P = \begin{bmatrix} P^F \\ P^D \end{bmatrix} \quad A = \begin{bmatrix} A^{FF} & A^{FD} \\ A^{DF} & A^{DD} \end{bmatrix} \quad V = \begin{bmatrix} V^F \\ V^D \end{bmatrix}. \quad (2)$$

Superscripts F and D denote the sets of fossil fuel sectors and non-fossil fuel sectors. P^X indicates the producer prices of sectors in set X , V^X indicates the cost for sectors in set X as a payment per unit production to the production factors, and A^{XY} indicates the cost of the sectors in set Y as a payment per unit production to sectors in set X . For example, P^F indicates the producer prices of fossil fuel sectors, and A^{FD} indicates the set of input coefficients from the fossil fuel sectors to the non-fossil fuel sectors. The superscript t indicates the transposition of a vector or a matrix. By substituting (2) for (1), the Leontief price model with externalized fossil fuel sectors can be represented as

$$P^D = (A^{FD})^t P^F + (A^{DD})^t P^D + V^D. \quad (3)$$

Second, domestic and imported products need to be distinguished from each other to focus on the influence from the price of imported fossil fuels to domestic products. For this purpose, equation (3) needs to be modified using the import coefficient vector, $M = [M^F, M^D]$, where the elements indicate the ratio of the imported product to all demand for sector j

as

$$\begin{aligned}
 P^D &= (\hat{M}^F A^{FD})^t P^F + \{(I^D - M^D)A^{DD}\}^t P^D + V^D \\
 &= (B^{FD} P^F)^t + (B^{DD} P^D)^t + V^D.
 \end{aligned} \tag{4}$$

M^X indicates the import coefficients for the sectors in set X , $B^{FD} = \hat{M}A^{FD}$ indicates the input coefficients from the imported fossil fuel sectors to the domestic sectors other than fossil fuels, $B^{DD} = (I^D - \hat{M})A^{DD}$ indicates the set of input coefficients among domestic sectors other than fossil fuels, and I^X indicates an identity matrix whose dimension is equal to that of A^{XX} . The mark \wedge indicates diagonalization of a vector.

All elements of P^F and P^D , the prices of imported fossil fuels and domestic products other than fossil fuels, are normalized to one in the equilibrium condition. When P^F increases by ΔP^F from the equilibrium condition, an increase in the rate of P^D , ΔP^D , can be estimated as

$$\begin{aligned}
 \Delta P^D &= (B^{FD})^t \Delta P^F + (B^{DD})^t \Delta P^D \\
 \Leftrightarrow \Delta P^D &= \{I^D - (B^{DD})^t\}^{-1} (B^{FD})^t \Delta P^F.
 \end{aligned} \tag{5}$$

2.1.2. Decomposition of the price increase into input factors

This section explains the method of decomposing ΔP^D into the constituent parts of various types of input: such as input from fossil fuel, energy conversion, and non-energy sectors. These constituent parts are denoted as the input factor of those sectors. Further, each input factor can be decomposed into direct and indirect input factors; the former indicates the direct influence upon the products, and the latter indicates the indirect influence passing through other sectors.

For this purpose, ΔP^D , B^{FD} , and B^{DD} are decomposed as

$$\Delta P^D = \begin{bmatrix} \Delta P^C \\ \Delta P^N \end{bmatrix} \quad B^{FD} = \begin{bmatrix} B^{FC} & B^{FN} \end{bmatrix} \quad B^{DD} = \begin{bmatrix} B^{CC} & B^{CN} \\ B^{NC} & B^{NN} \end{bmatrix}, \quad (6)$$

where C and N denote the sets of energy conversion and non-energy sectors.

ΔP^X indicates an increase in the rate of producer prices of sectors in set X ,

and B^{XY} indicates the input coefficients from the sectors in set X to the

sectors in set Y . By substituting (6) for (5), we obtain

$$\Delta P^C = \{I^C - (B^{CC})^t\}^{-1} \{(B^{FC})^t \Delta P^F + (B^{NC})^t \Delta P^N\} \quad (7)$$

and
$$\Delta P^N = \{I^N - (B^{NN})^t\}^{-1} \{(B^{FN})^t \Delta P^F + (B^{CN})^t \Delta P^C\}. \quad (8)$$

For energy conversion sectors, we decompose ΔP^C into input factors of three types of fossil fuels and non-energy products. ΔP^F can be decomposed into increases in the prices of each fossil fuel, i.e., coal, crude

oil, and natural gas, as

$$\Delta P^F = \Delta P_{COAL}^F + \Delta P_{OIL}^F + \Delta P_{GAS}^F, \quad (9)$$

where the element of ΔP_k^F corresponding to fossil fuel k is equal to that of ΔP^F , and other elements are zero. By substituting (9) for (7), we obtain

$$\Delta P^C = \Delta P_{COAL}^C + \Delta P_{OIL}^C + \Delta P_{GAS}^C + \Delta P_{NE}^C \quad (10)$$

where $\Delta P_{COAL}^C = \{I^C - (B^{CC})^t\}^{-1} (B^{FC})^t \Delta P_{COAL}^F$ $\Delta P_{OIL}^C = \{I^C - (B^{CC})^t\}^{-1} (B^{FC})^t \Delta P_{OIL}^F$

$$\Delta P_{GAS}^C = \{I^C - (B^{CC})^t\}^{-1} (B^{FC})^t \Delta P_{GAS}^F \quad \Delta P_{NE}^C = \{I^C - (B^{CC})^t\}^{-1} (B^{NC})^t \Delta P_{NE}^N.$$

The first, second, and third term of (10) indicate the input factors of imported coal, crude oil, and natural gas, respectively, and the fourth term indicates input factor of domestic non-energy products, respectively. When all the diagonal elements in ΔP^F are set to one, ΔP^C represents the fossil fuel price elasticity in each energy conversion sector, and the four terms on the right side of equation (10) represent the decomposition of the price elasticity into each input factor. These four terms can be further decomposed into direct and indirect influence. For example, ΔP_{COAL}^C can be decomposed as

$$\begin{aligned} \Delta P_{COAL}^C &= [I^C + (B^{CC})^t + \{(B^{CC})^t\}^2 + \{(B^{CC})^t\}^3 + \dots] (B^{FC})^t \Delta P_{COAL}^F \\ &= (B^{FC})^t \Delta P_{COAL}^F + \sum_{i=1}^{\infty} \{(B^{CC})^t\}^i (B^{FC})^t \Delta P_{COAL}^F, \end{aligned} \quad (11)$$

where the first and second terms indicate the direct and indirect input factors

of imported coal, respectively. Other input factors in equation (10) can also be similarly decomposed into direct and indirect factors.

For non-energy sectors, we decompose ΔP^N into input factors of three imported fossil fuels and four final energies converted in Japan. ΔP^C can be decomposed into the increase in the prices of each final energy as

$$\Delta P^C = \Delta P_{OP}^C + \Delta P_{CP}^C + \Delta P_{ELE}^C + \Delta P_{TG}^C, \quad (12)$$

where the element of ΔP_{CP}^C corresponding to final energy h is equal to that of ΔP^C , and the other elements are zero. Subscripts OP , CP , ELE , and TG indicate the oil products, coal products, electricity, and the city gas sector, respectively. By substituting (9) and (12) for (8), we obtain

$$\Delta P^N = \Delta P_{COAL}^N + \Delta P_{OIL}^N + \Delta P_{GAS}^N + \Delta P_{OP}^N + \Delta P_{CP}^N + \Delta P_{ELE}^N + \Delta P_{NE}^N, \quad (13)$$

where $\Delta P_{COAL}^N = \{I^N - (B^{NN})^t\}^{-1} (B^{FN})^t \Delta P_{COAL}^F$ $\Delta P_{OIL}^N = \{I^N - (B^{NN})^t\}^{-1} (B^{FN})^t \Delta P_{OIL}^F$

$$\Delta P_{GAS}^N = \{I^N - (B^{NN})^t\}^{-1} (B^{FN})^t \Delta P_{GAS}^F \quad \Delta P_{OP}^N = \{I^N - (B^{NN})^t\}^{-1} (B^{CN})^t \Delta P_{OP}^C$$

$$\Delta P_{CP}^N = \{I^N - (B^{NN})^t\}^{-1} (B^{CN})^t \Delta P_{CP}^C \quad \Delta P_{ELE}^N = \{I^N - (B^{NN})^t\}^{-1} (B^{CN})^t \Delta P_{ELE}^C$$

$$\Delta P_{TG}^N = \{I^N - (B^{NN})^t\}^{-1} (B^{CN})^t \Delta P_{TG}^C$$

The first, second, and third terms of (13) indicate the input factors of fossil fuels, and the fourth, fifth, sixth, and seventh terms indicate those of final energies. When all the diagonal elements in ΔP^F are set to one, ΔP^N

represents the energy price elasticity in each non-energy sector, and the seven terms on the right side of equation (13) represent the decomposition of the price elasticity. These seven terms can also be decomposed into direct and indirect input factors in the same manner in equation (11).

2.2. The risk of increase in the producer price in non-energy sectors

This section reviews the definition of the index of the risk (CVaR) adopted in this study in terms of the portfolio approach and explains how we combine the Leontief price model and the portfolio approach.

The four types of risk index commonly applied in the energy portfolio analysis are variance, semivariance, value-at-risk (VaR), and conditional value-at-risk (CVaR). The characteristics of these indices are summarized schematically in Figure 2. For a risk analysis of changes in the energy price (or the returns of energy businesses), the variance in the cost of an energy mix has been the most commonly used (Bar-Lev and Katz, 1976; Humphreys and McClain, 1998; Awerbuch and Berger, 2003; Roques et al., 2008). However, a variance increases not only when energy prices are increased

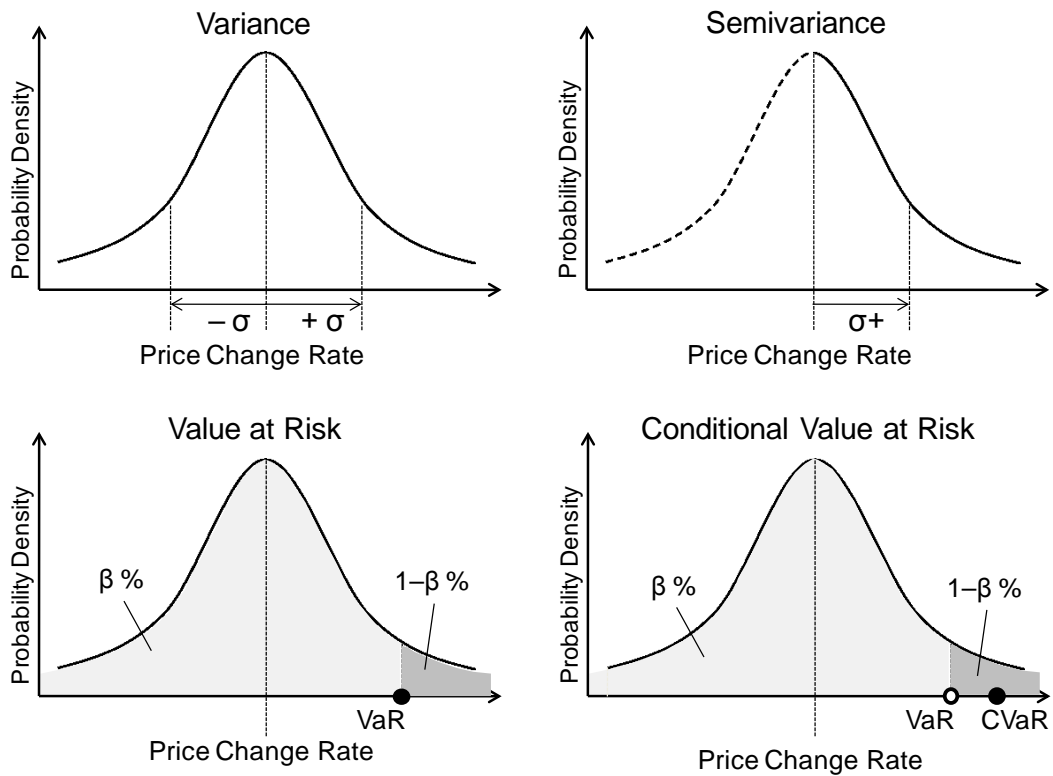


Figure 2. Difference among four indices of risk.

but also when they are decreased because it is defined as the squared average of price deviations both above and below an expected price.

Therefore, a variance is not a precise measure of risk for energy consumers who suffer from only energy price increase and who obtain some benefits from energy price decrease. Instead, Yu (2007) proposed to use semivariance in the cost of an energy mix; that is defined as a squared average of only price deviations above an expected value and applied in a case study of the American electricity market. Another substitution of a

variance is VaR defined as the maximum cost of an energy mix with a given level of confidence. An advantage of VaR is that it can focus on extreme changes in the cost. Liu and Wu (2007) and Deng and Xu (2009) used VaR to measure the risk in electricity markets. However, VaR possesses two disadvantages: ignoring the shape of tail distribution, and undesirable mathematical characteristics such as a lack of subadditivity, convexity, and positive homogeneity⁴ (Artzner et al., 1997; Artzner et al., 1999; Rockafellar and Uryasev, 2000). Fortin et al. (2008) proposed to use CVaR defined as the conditional expected cost of energy mix beyond the given level of confidence because it can consider a shape of the tail distribution of the cost, and it has subadditivity, convexity, and positive homogeneity. Bartelj et al. (2009) used CVaR to measure risk in electricity markets. CVaR was also adopted by studies analyzing a risk of catastrophic events on a large-scale infrastructure and economic system (Lian et al., 2007; Santos, 2008; Santos et al., 2008).

This study uses CVaR as a measure of the risk of an increase in the producer prices in domestic non-energy sectors. We do not use variance and semi-variance because we would like to focus on a tail distribution rather than on a deviation from expected value to quantify the risk of an extreme

increase in the prices of imported fossil fuels. We choose CVaR over VaR because the risk index needs to satisfy positive homogeneity for it to be decomposed into input factors.

As shown in equation (8), an increase in the producer prices in the non-energy sectors, ΔP^N , is a function of input coefficient matrix A , import coefficient matrix, M , and an increase in the prices of imported fossil fuels, ΔP^F . The probability that an increase in the producer price of non-energy sector j does not exceed a threshold level α is given by

$$\Psi(A, M, \Delta P^F) = \Pr_{\Delta p_j^N \leq \alpha} (A, M, \Delta P^F), \quad (14)$$

where Δp_j^N indicates an increase in the producer price of non-energy sector j , i.e., the j th element of ΔP^F , and $\pi(\Delta P^F)$ indicates a probabilistic density function of ΔP^F . Then, β -VaR, indicating a minimum Δp_j^N with a given level of confidence β , is defined as

$$\text{VaR}_{\beta j}(A, M, \Delta P^F) = \min\{ \Delta p_j^N \mid \Psi(A, M, \Delta P^F) \geq \beta \}. \quad (15)$$

β -CVaR, indicating a conditional expected value of Δp_j^N beyond the given level of confidence β , is defined as

$$\begin{aligned} \text{CVaR}_{\beta j}(A, M, \Delta P^F) &= E(\Delta p_j^N \mid \Psi(A, M, \Delta P^F) > \beta) \\ &= (1 - \beta)^{-1} \int_{\Delta p_j^N \geq \alpha_{\beta}(A, M)} \Delta p_j^N \pi(\Delta P^F) d\Delta P^F \end{aligned} \quad (16)$$

The yearly change in the price of imported fossil fuel is modeled with Geometric Brownian Motion (GBM) in this study. The price of fossil fuel i in year τ , $q_i(\tau)$, can be represented as

$$\ln q_i(\tau) - \ln q_i(0) = (\mu_i - \frac{1}{2}\sigma_i^2)\tau + \sigma_i \varepsilon_i \quad (17)$$

where μ_i is a drift parameter, σ_i is a volatility parameter, ε_i is a random variable following $N(0, \sigma_i^2)$, and two random variables ε_i and ε_j are correlated with ρ_{ij} . Since an yearly change in the price of imported fossil fuel i can be expressed as $\Delta p_i^F(\tau) = q_i(\tau) / q_i(0) - 1$, equation (17) can be rewritten as

$$\Delta p_i^F(\tau) = \exp\{(\mu_i - \frac{1}{2}\sigma_i^2)\tau + \sigma_i \varepsilon_i\} - 1 \quad (18)$$

By setting $\Delta p_i^F(0)$ as one for all i and then running a Monte Carlo simulation, the probabilistic density function of yearly change in Δp_i^F can be estimated.

Finally, β -CVaR in the non-energy sectors are decomposed into input factors of each fossil fuel and final energies by substituting (13) into (16) as

$$\begin{aligned} CVaR_{\beta,j}(A,M) &= (1-\beta)^{-1} \int_{\Delta p_j^N \geq \alpha_\beta(A,M)} \Delta p_j^N u_j P^N (P^F) d P^F \\ &= (1-\beta)^{-1} \int_{\Delta p_j^N \geq \alpha_\beta(A,M)} \left(\Delta p_j^{COAL} + \pi \frac{N}{OIL} + \frac{N}{GAS} \right) (P^F) d P^F \\ &+ (1-\beta)^{-1} \int_{\Delta p_j^N \geq \alpha_\beta(A,M)} \left(\Delta p_j^{ELE} + \frac{N}{TG} \right) (P^F) d P^F \quad (19) \end{aligned}$$

where u_j is a vector whose dimension is equal to ΔP^N , the j th element is set to

be one, and other elements are zero.

3. Data and results

3.1. Fossil fuel price elasticity

3.1.1. I-O tables used for the analysis

Coefficients A and M in the Leontief price model are calculated from the time series input-output tables (TSIO) (Kawashima, 2005) for the period 1970–2000. Although the tables have 155 standardized sectors, we reclassified them into 37 sectors for simplicity. Table 1 lists the names and the numbers of each sector.

In this study, we do not report the results of the unknown sector (No. 37) because it includes errors caused by incomplete data. Although the total input and output values in each sector must be equal for the I-O analysis, they were not equal when the table was created by accumulating surveyed data. To solve this problem, the total input and output values are modified to

Table 1. Names and numbers of each sector in TSIO classified into 37 sectors.

No	Name	No	Name
1	coal	20	transit machines
2	crude oil	21	precision machines
3	natural gas	22	other manufacturing products
4	oil products	23	civil engineering
5	coal products	24	water services & waste disposal
6	electricity generation	25	commerce
7	town gas & heat supply	26	finance & insurance
8	agriculture, forestry, and fishing	27	estate agency
9	mining	28	transport
10	food products	29	communication & broadcasting services
11	fiber products	30	civil service
12	pulp, paper, and wood products	31	education & research
13	chemical products	32	medical and social security
14	cement	33	other public services
15	steel	34	business services
16	nonferrous metals	35	consumer services
17	metal products	36	deskwork products
18	general industrial machines	37	unknown
19	electric machines		

be equal by adjusting the values in the unknown sector.

Moreover, we do not discuss the results of the other manufacturing products sector (No. 22) in 2000. In this year, the input and output values related to the payback and manufacturing of recycled resources were newly introduced into the survey, and energy consumption for the recycle was considered as the input to the other manufacturing products sector. As a result, the Δp_j^N of the sector in 2000 could be much larger than that in 1990, and it is difficult to clarify how much percentage of the change in the Δp_j^N during the 1990s was caused by the change in statistical classification.

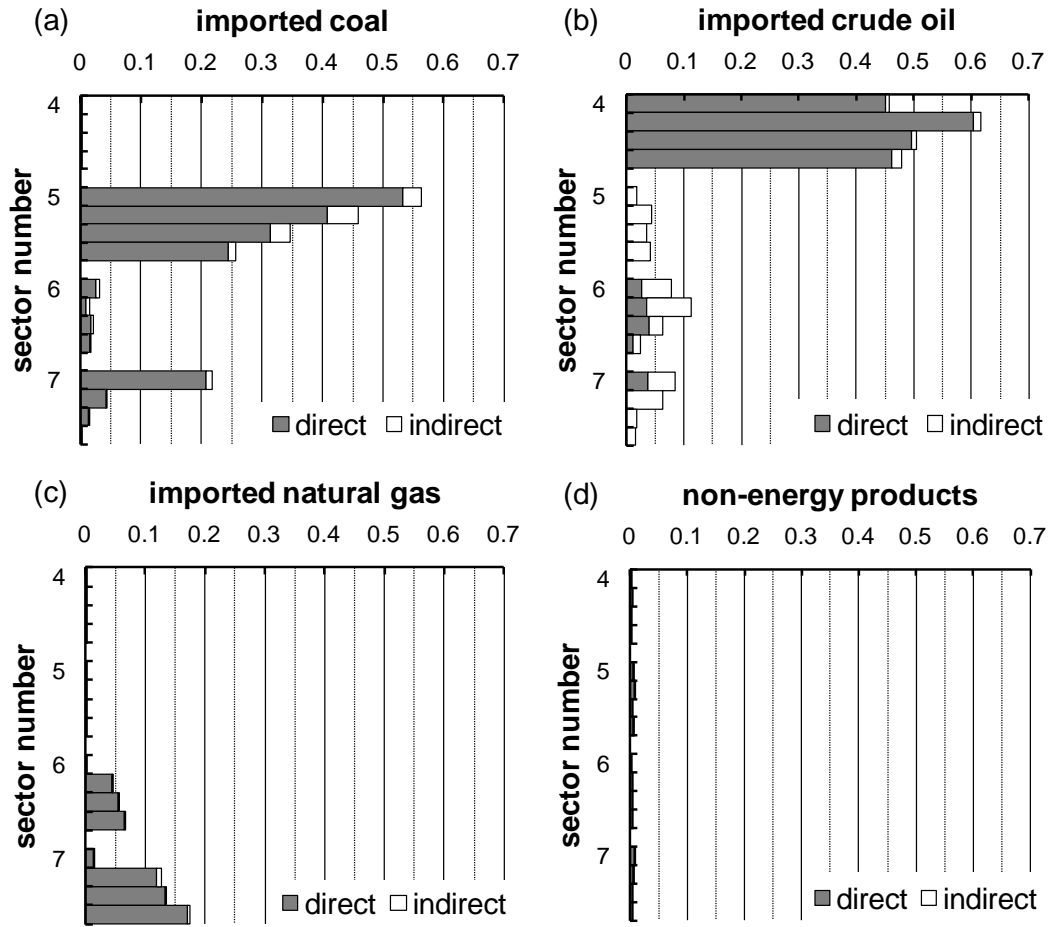


Figure 3. Fossil fuel price elasticity in producer prices of each energy conversion sector. (a), (b), (c), and (d) present the input factors of imported coal, crude oil, natural gas, and non-energy products, respectively.

3.1.2. The elasticity of energy conversion sectors

Figure 3 presents the fossil fuel price elasticity in the producer prices in the energy conversion sectors, i.e., the value of ΔP^C against a unitary increase in P^F , decomposed into four input factors. (a), (b), (c), and (d)

present the input factors of imported coal, crude oil, natural gas, and non-energy products, respectively. These input factors are further decomposed into direct and indirect factors.

In the oil products sector (No. 4), direct input factor of imported crude oil increased in the 1970s and decreased in the 1980s. The increase in the elasticity in the 1970s was due to the two oil crisis, which decreased the demands for oil products through the recession and improvement of energy usage. Thus, the lack of demand increased the cost of production through the decrease of the availability factor. On the other hand, the decrease in the 1980s was caused by the change in the product mix in addition to the recovery of demand. The share of oil products with high added value (i.e., light oil, kerosene, naphtha, and gasoline) increased from 52% in 1980 to 66% in 1990 (Kawashima, 2005). However, the decrease in the 1980s could not compensate for the increase in the 1970s; the input factor in 2000 was larger than that in 1970.

In the coal products sector (No. 5), the direct input factor of imported coal was decreased through the analysis period. Improvements in the production process, such as the installation of large heat recovery systems

like coke dry quenching equipment, contributed to the decrease in the input factor (JISF, 2009).

In the electricity sector (No. 6), both the direct and indirect input factors of imported crude oil decreased through the analysis period. In this sector, the direct and indirect factors correspond to the consumption of crude oil and heavy oil, respectively. Japan had replaced crude-oil- and heavy-oil-fired power plants with gas-fired and nuclear power plants. As a result, the input factor of imported gas increased.

In the town gas sector (No. 7), the direct input factors of both imported coal and crude oil decreased, and that of imported natural gas are increased. This change was caused by the substitution of materials for producing town gas from coal and oil gas to natural gas after the oil crises. The share of natural gas in the total material increased greatly from 15.1% in 1970 to 87.2% in 2000.

In all the energy conversion sectors, the input factors of non-energy products were much smaller than those of fossil fuels; hence, they can be ignored.

3.1.3. The elasticity of non-energy sectors

Figure 4 presents the fossil fuel price elasticity in the producer prices in the non-energy sectors, i.e., the value of ΔP^N against a unitary increase in P^F , decomposed into seven input factors: three input factors of fossil fuels and four input factors of final energies. In Figure 4, the input factors of coal, crude oil, and natural gas are totaled with that of coal products, oil products, and town gas, respectively. This simplification is valid because non-energy sectors use much more final energies than primary energies. (a), (b), (c), and (d) present the input factors of coal products plus imported coal, oil products plus imported crude oil, town gas plus imported natural gas, and electricity, respectively. These input factors can be further decomposed into direct and indirect factors.

In the primary industry and material industry sectors, such as agriculture (No. 8), mining (No. 9), chemical products (No. 13), and cement (No. 14) sectors, the direct input factors of oil products were relatively large. The main usages in those sectors are heating for greenhouses in the agriculture sector, machine engines in the mining sector, feedstock in the

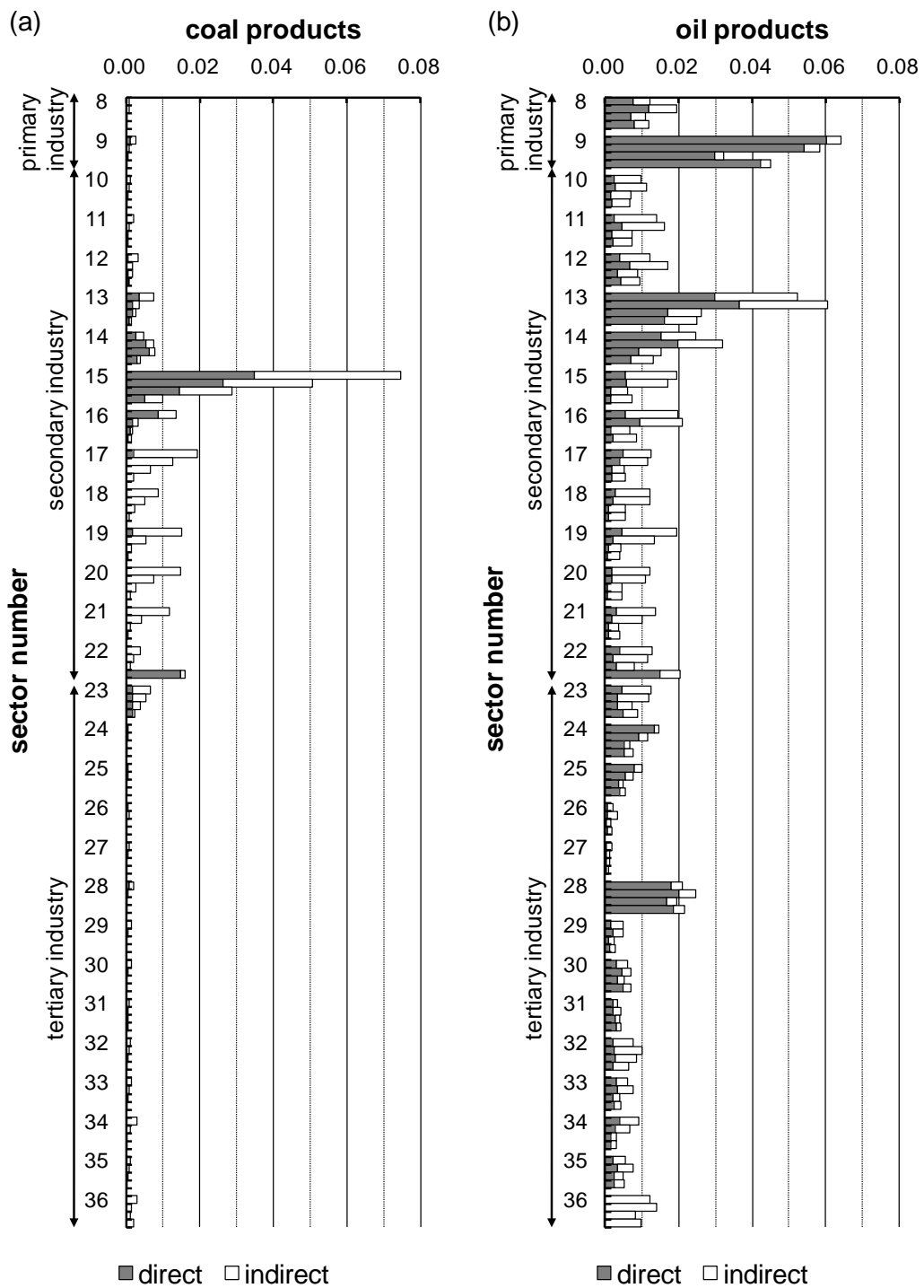
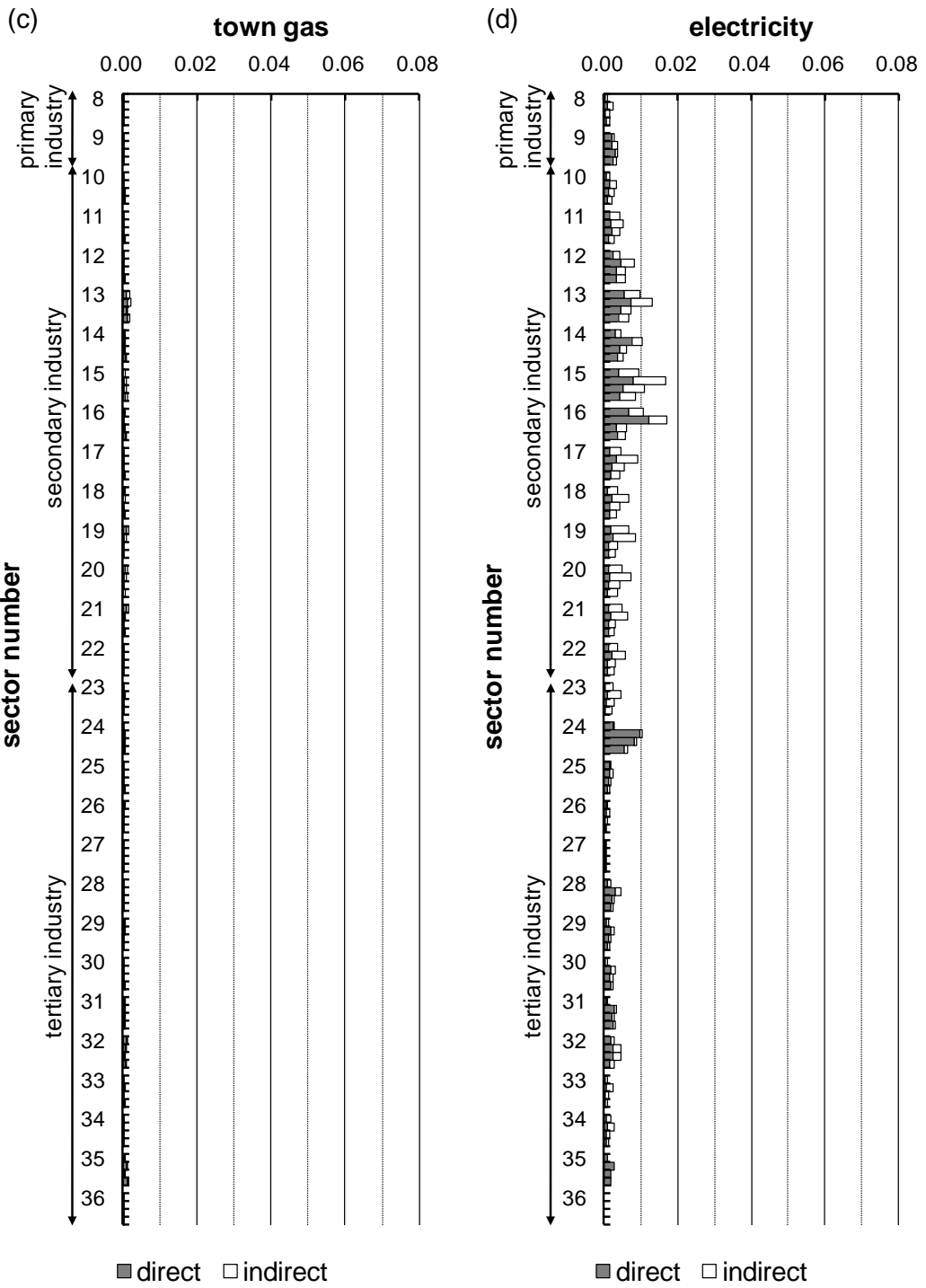


Figure 4. Fossil fuel price elasticity in the producer price of each non-energy sector. (a), (b), (c), and (d) present the input factors of coal products plus imported coal, oil products plus imported crude oil, town gas plus imported natural gas, and electricity, respectively.



(Figure 4. continued)

chemical product sector, and heating for the firing process in the cement sector. Input factors of the other energies are relatively small. In the chemical products and cement sectors, the indirect input factors of oil products were also large because internal flows within these sectors were regarded as indirect inputs. The internal flow indicates input from an upstream process to a downstream process; for example, input from the production process of ethylene to that of plastic.

In the chemical products sector, both the direct and indirect input factors of oil products greatly decreased during the analysis period due to enhancement of heat recovery systems, growth in the size of facilities, and the rise in the availability factor. The cement sector also replaced heavy oil with coal; which caused an increase in the input factor of coal. On the other hand, the agriculture sector did not decrease the input factor of oil products, and the mining sector rather increased this factor in 1990. This is because of a decline in the mining sector in Japan, worsening the availability factor and the rate of added value in this sector. However, this change seldom influenced other sectors because the mining sector's production was very small, occupying only 0.1% of the total production in Japan in 2000.

The steel sector (No. 15) had the largest direct and indirect input factors of coal products. The direct factor was caused by the input of coke and fuel coal for reduction and heating, and the indirect factor was mainly caused by the internal flows; for example, input from the production process of crude steel to the rolling or casting processes. This factor decreased through the analysis period due to improvements in both the coal products sector and the steel sector. Its own improvements include the installation of large heat recovery systems, the development of products with high added value, and the expansion of use of wastes, such as plastic waste and discarded tires, for heating. These improvements have also decreased the input factor of oil products during the same period.

In the assembly sectors, such as metal products (No. 17), general industrial machines (No. 18), electric machines (No. 19), transit machines (No. 20), and precision machines (No. 21) sectors, almost all elements of input factors were indirect factors because these sectors use much more non-energy materials than energies for production. The indirect input factors of coal products is mainly caused by the input of steel, and that of oil products were mainly caused by chemical products because they were the main

materials for assembly sectors and had high direct input factors. As the direct factors in chemical products and the steel sector decrease, the indirect factors in these assembly sectors also decrease.

In almost all the service sectors, the input factors of all energies were relatively smaller than that in the manufacturing sectors, and the decreases through the analysis period were also small. The exceptions were the water services and waste disposal (No. 24), commerce (No. 25), and transport (No. 28) sectors, whose direct input factors of oil products were relatively large. The main usages are for pump engines in the water services and waste disposal sector, for air conditioning in the commerce sector, and for automobile engines in the transport sector. In the water services and waste disposal sector, the input factor of oil products decreased and that of electricity increased. This change was caused by the replacement of substituting engine pumps with motor pumps.

The input factors of electricity in many sectors have showed a trend similar to that of crude oil in the electricity sector, indicating that oil substitution in the electricity sector decreased it as an input factor in the non-energy sectors. However, the input factors of electricity increased

slightly in some service sectors, such as the education and research (No. 30) and the medical and social security (No. 31) sectors. This increase was mainly caused by the replacement of oil with electricity and the automation of offices. The input factors of town gas were smaller than those of other energies because town gas occupies only a small share of energy demand for industrial sectors in Japan. The share was 5% even in 2000. Although the input factor of fossil fuels in the oil products sector did not decrease (Figure 3), the input factors of oil products decreased in almost all the non-energy sectors. It indicates that the non-energy sectors decreased their input factors by their own improvements.

The sharp increase in the input factors of coal products and oil products in the other manufacturing (No. 21) sector was possibly caused by the change in statistical classification explained in 3.1.1.

3.2. I-O portfolio analysis

3.2.1. Characteristics of change in the price of fossil fuels

In the chapter 3.1, we estimated the fossil fuel price elasticities of the non-energy sectors, and clarified the causes of decrease in the elasticities by decomposing them. However, we need to estimate the uncertainty in the price of fossil fuels in addition to the elasticities to estimate the CVaR of the sectors. In this subchapter, we estimate the probabilistic density function of an increase in the prices in fossil fuels, $\pi(\Delta P^F)$, from the equation (18). The parameters for equation (18) can be estimated from the yearly data on the prices of imported fossil fuels (JTA, 1970–2000). Since these imported prices are CIF prices on a yen basis, they include changes in the exchange rate and cost for transport and insurance from the supplying country to Japan. Table 2 lists the estimated parameters, and Figure 5 presents the $\pi(\Delta P^F)$ estimated by the Monte Carlo simulation. The number of iterations is 50000.

Both the drift and the volatility parameters in the price of crude oil and natural gas have almost the same value while the parameters in the price of natural gas are slightly small. On the other hand, the price of coal has a negative drift and a much lower volatility than the price of crude oil and natural gas. The correlation coefficient between the price of crude oil and natural gas is higher than that between the price of coal and crude oil and

Table 2. Estimated parameters in the prices of each fossil fuel.

drift parameter		volatility parameter		correlation coefficient	
μ_{COAL}	-0.0183	σ_{COAL}	0.190	$\rho_{\text{COAL,OIL}}$	0.705
μ_{OIL}	0.00360	σ_{OIL}	0.238	$\rho_{\text{OIL,GAS}}$	0.849
μ_{GAS}	0.00095	σ_{GAS}	0.230	$\rho_{\text{GAS,COAL}}$	0.709

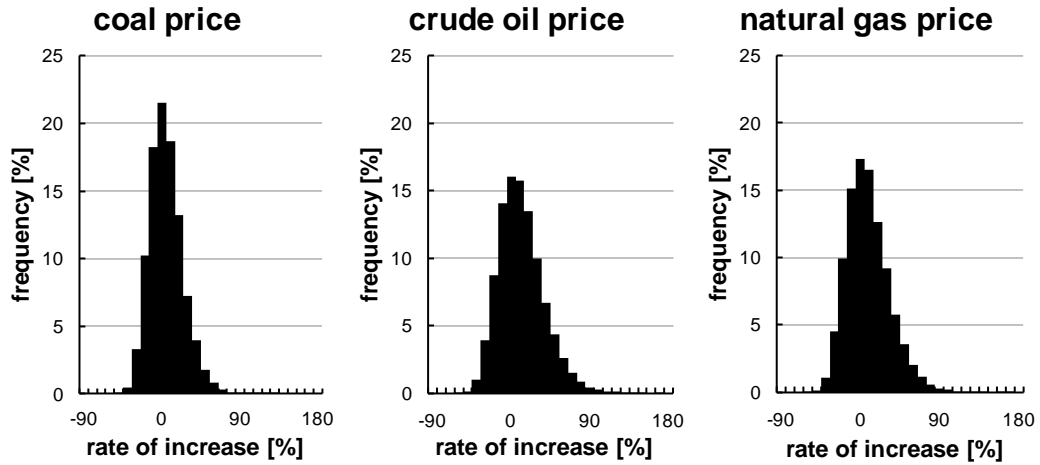


Figure 5. Probabilistic distribution in the prices of imported fossil fuels [%].

between coal and natural gas. These results indicate that the prices of crude oil and natural gas have a higher probability of increase than the price of coal, and the prices of crude oil and natural gas have a tendency to increase simultaneously.

3.2.2. Risk of price increase in non-energy sectors

The CVaR, an index of the risk of an increase in the producer prices

in the non-energy sectors, can be estimated from the fossil fuel price elasticity and the probabilistic density function of an increase in the prices in fossil fuels by applying the equation (16). Further, the CVaR in the non-energy sectors are decomposed into the input factors of each type of energy by applying the equation (19). The value of β is set to 99%⁵. Figure 6 (a) presents the CVaR in the non-energy sectors, i.e., conditional expected value in ΔP^N against a yearly increase in P^F , decomposed into seven input factors: three input factors of fossil fuels and four input factors of final energies. In Figure 4, the input factors of coal, crude oil, and natural gas are totaled with those of coal products, oil products, and city gas, respectively. Figure 6 (b) presents changes in the CVaR, during the period 1970–2000, further decomposed into changes in direct and indirect factors. The first bar represents the change in direct input factors, and the second bar represents the change in indirect input factors.

Almost all sectors decreased their CVaR through the analysis period. These sectors can be categorized into three groups based on breakdowns of the changes in the CVaR: sectors that decreased primarily their direct input factors, sectors that decreased both direct and indirect input factors, and

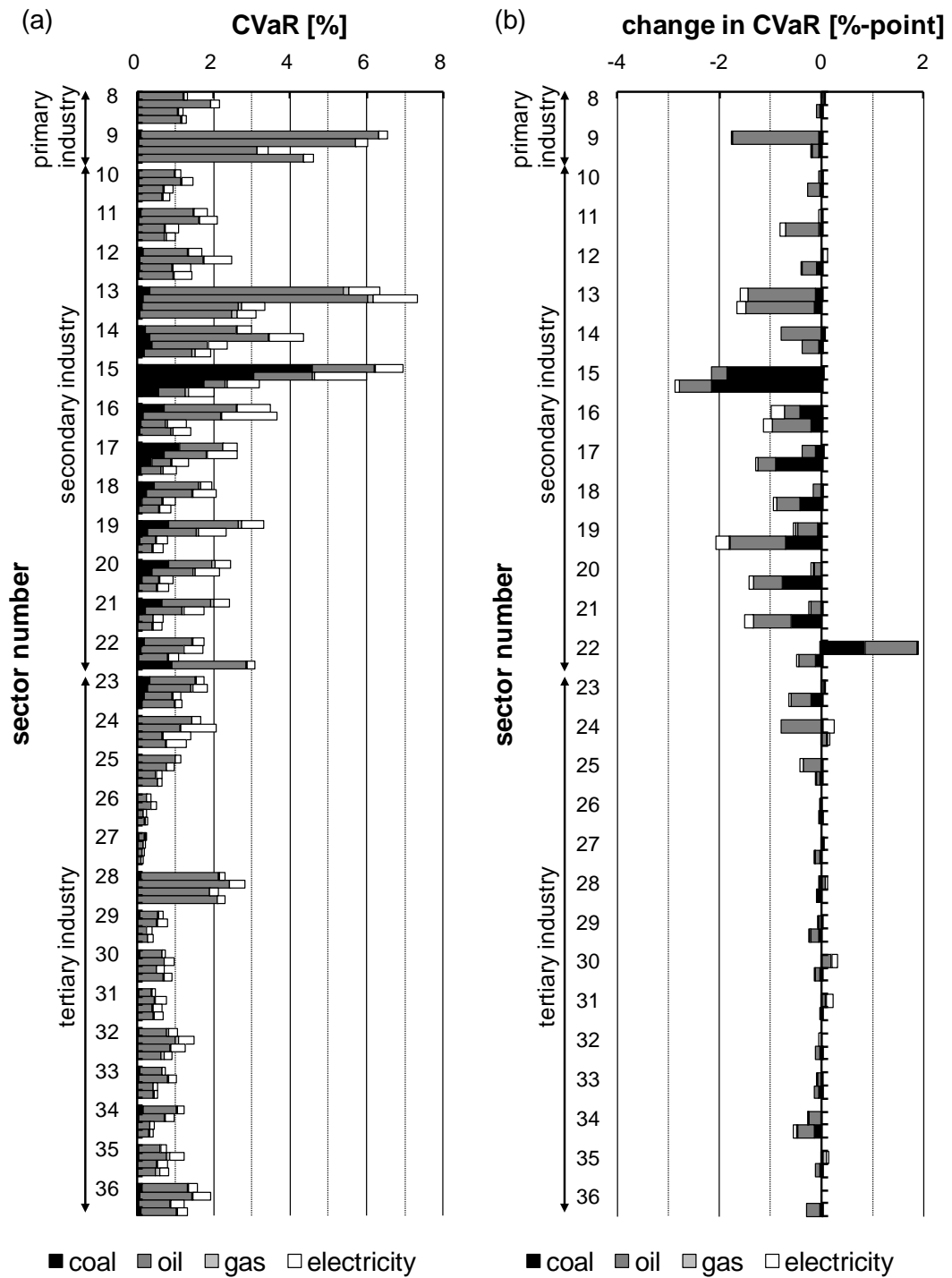


Figure 6. (a) CVaR in the producer prices of each non-energy sector ($\beta = 1\%$). (b) change in the CVaR during 1970–2000. The first bar represents the change in direct input factors, and the second bar represents the change in indirect input factors.

sectors that decreased primarily their indirect input factors.

The mining (No. 9), cement (No. 14), water services and waste disposal (No. 24), and commerce (No. 25) sectors decreased primarily their direct input factors of oil products. Since the input factor of fossil fuels in the oil products sector did not decrease during the analysis period, these sectors decreased their CVaRs by their own improvements, such as energy saving and oil replacement. These sectors have seldom received a benefit from a decrease in the CVaR in other non-energy sectors because indirect input factors of their CVaRs were seldom decreased.

The chemical products (No. 13), steel (No. 15), and non-ferrous metals (No. 16) sectors have decreased both the direct and indirect input factors of their CVaRs. The chemical products sector primarily decreased the input factor of oil products, the steel sector primarily decreased the input factor of coal products, and the non-ferrous metals sector decreased the input factors of both coal and oil products. While the direct input factor of the steel sector decreased by the improvement in both the coal products sector and the steel sector itself, the direct input factor of the chemical products sector decreased mainly through its own improvements. Improvements in

internal flows contributed to the decrease in indirect input factors of the CVaRs in these sectors.

The assembly sectors, such as the metal products (No. 17), general industrial machines (No. 18), electric machines (No. 19), transit machines, (No. 20) and precision machines (No. 21), and business services (No. 34) sectors mainly decreased their indirect input factors of coal and oil products.

The decrease in the assembly sectors was caused by that in the material sectors, such as chemical products and steel, which provide main materials for the assembly sectors. The decrease of the indirect input factors in the business services sector was caused by the decrease in the assembly sectors because the business services sector mainly consists of the rental and maintenance of industrial machines.

Although, in general, the decrease in the CVaR during the analysis period was larger because the CVaR in 1970 was larger, the agriculture (No. 8) and transport (No. 28) sectors were the exceptions; the CVaR in these sectors did not decrease through the analysis period. As a result, the CVaR in these sectors became larger than that in the assembly sectors in 2000. In both sectors, the direct input factor of oil products occupied the main part of

the CVaR.

These results indicate that the decrease in a CVaR and its breakdown depend on the location of in the hierarchical structure of industries. For the sectors located in the upstream part of the structure, e.g., primary industries and material sectors, the CVaR can be decreased only by decreasing their direct input factors. On the other hand, for the sectors in the downstream part of the structure, e.g., assembly sectors, CVaR can be decreased only by decreasing their indirect input factors. The direct input factors in a sector can be decreased by either improvement of energy usage in that sector or an energy conversion sector providing energy to that sector. Sectors mainly consuming coal products possibly decreased their CVaR regardless of their own improvement in energy use because the coal products sector decreased its fossil fuel price elasticity. However, sectors mainly consuming oil products possibly decreased their CVaR only if they improved their own energy intensity. The indirect input factors in a sector can be decreased as a result of risk reduction in upstream sectors. Thus, the reduction of risk in assembly sectors is the result of improvements in energy usage by material sectors rather than by assembly sectors themselves. In

the chemical products, steel, and non-ferrous metals sectors, both the direct and indirect factors largely decreased. In these sectors, decrease in the direct input factors could also decrease the indirect input factors because the indirect input factors in these sectors were caused mainly by internal flows.

3.2.3. Relationship among energy cost, profit, and risk

In the previous subchapter, we have analyzed the cause of the risk reduction in the non-energy sectors through the analysis period. In this subchapter, we analyze the relationship among the change in the CVaR, the energy cost per unit production, and the rate of added value, i.e., the added value per unit of production. By comparing the change in the CVaR and energy cost per unit production, the contribution of the improvement in energy usage to the risk reduction can be clarified for each sector. By comparing the change in the CVaR and the rate of added value, the relationship between the increase in profit and the reduction in the risk can be clarified. The energy intensity and the rate of added value can be estimated from Kawashima (2005).

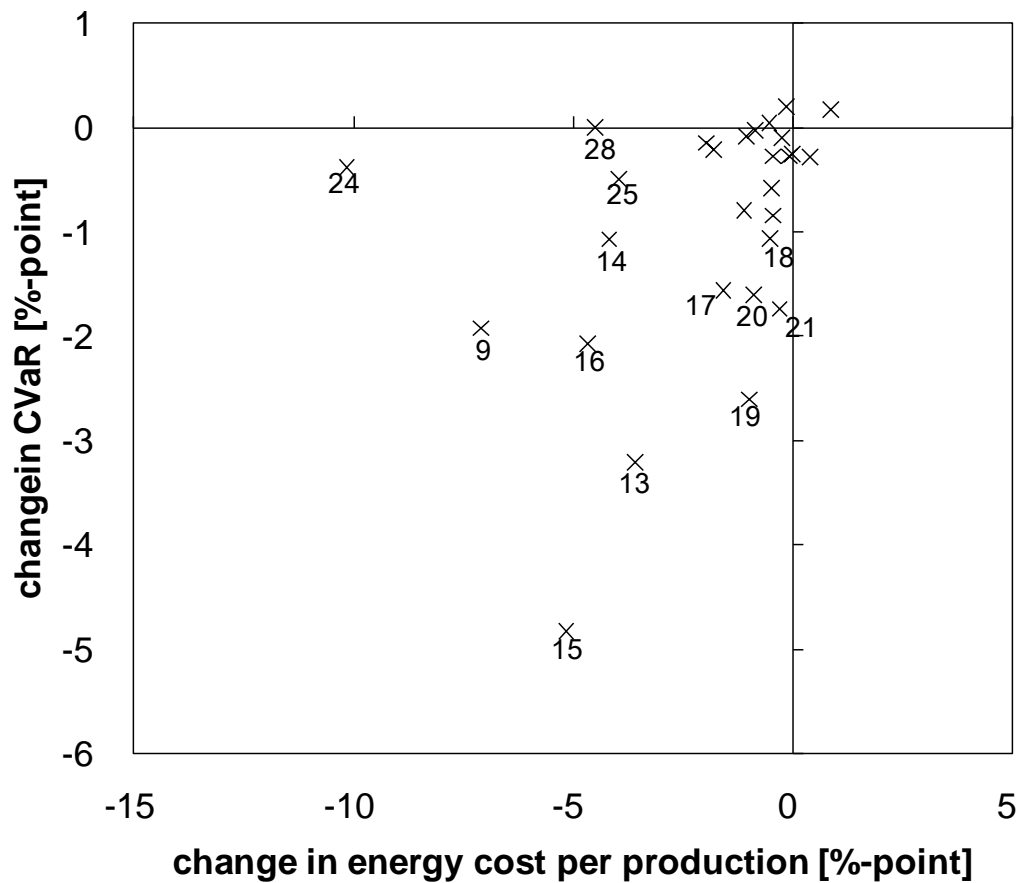


Figure 7. Relationship between the change in the energy cost per production and CVaR during the analysis period.

Figure 7 presents the relationship between the change in the energy cost per production and the CVaR through the analysis period. In the sectors that decreased only direct input factors, i.e., the cement (No. 14), water services and waste disposal (No. 24), commerce (No. 25), and transport (No. 28) sectors, decrease in the CVaR was relatively small regardless of the relatively large decrease in the energy cost per production. On the other

hand, in the sectors that decreased both their direct and indirect input factors, i.e., the chemical products (No. 13), steel (No. 15), and non-ferrous metals (No. 16) sectors, both the CVaR and the energy cost per production were relatively large. This indicates that the material sectors with larger internal flows can benefit more by the decrease in the energy cost. In the sectors that decreased only their indirect input factors, i.e., the assembly sectors (No. 17–21), decrease in the CVaR is relatively large regardless of the relatively small decrease in the energy cost per production. The CVaR in these sectors decreased as a result of risk reduction in the upstream sectors rather than their own improvement in energy usage.

This result is consistent with those in the previous subsection; the sectors in the downstream part of the industrial structure can benefit from the improvement of energy usage by the sectors in the upstream part of the industrial structure. A decrease in the fossil fuel price elasticity of the coal products sector decreased the risk in the steel and non-ferrous metals sectors, and has further contributed to the decrease in the risk of the assembly sectors. On the other hand, the fossil fuel price elasticity of the oil products sector did not decrease through the analysis period. Thus, the

degree of decrease in the direct input factors of oil products depends on the effort to improve the energy usage in each sector. In the chemical and non-ferrous metals sectors, both the direct and indirect factors decreased, and, as a result, the risk of the assembly sectors also decreased. In the cement, water services and waste disposal, commerce, and transport sectors, the decrease in the risk was relatively small because they could not benefit from the improvement in other non-energy sectors.

Figure 8 presents the relationship between the change in the rate of added value and the CVaR through the analysis period. Although the service sectors, such as civil engineering (No. 23), civil service (No. 30), other public services (No. 33), and business services (No. 34) largely increased the rate of added value, their CVaR seldom decreased. In these sectors, an increase in added values achieved through efforts not related to energy, such as the upskilling of workers, office automation, and rationalization of distribution. Even in the manufacturing sectors consuming much more energy than service sectors, a correlation between the change in the rate of added value and the CVaR cannot be found. In fact, a portion of the increase in the added value was caused by these sectors' improvements in energy usage.

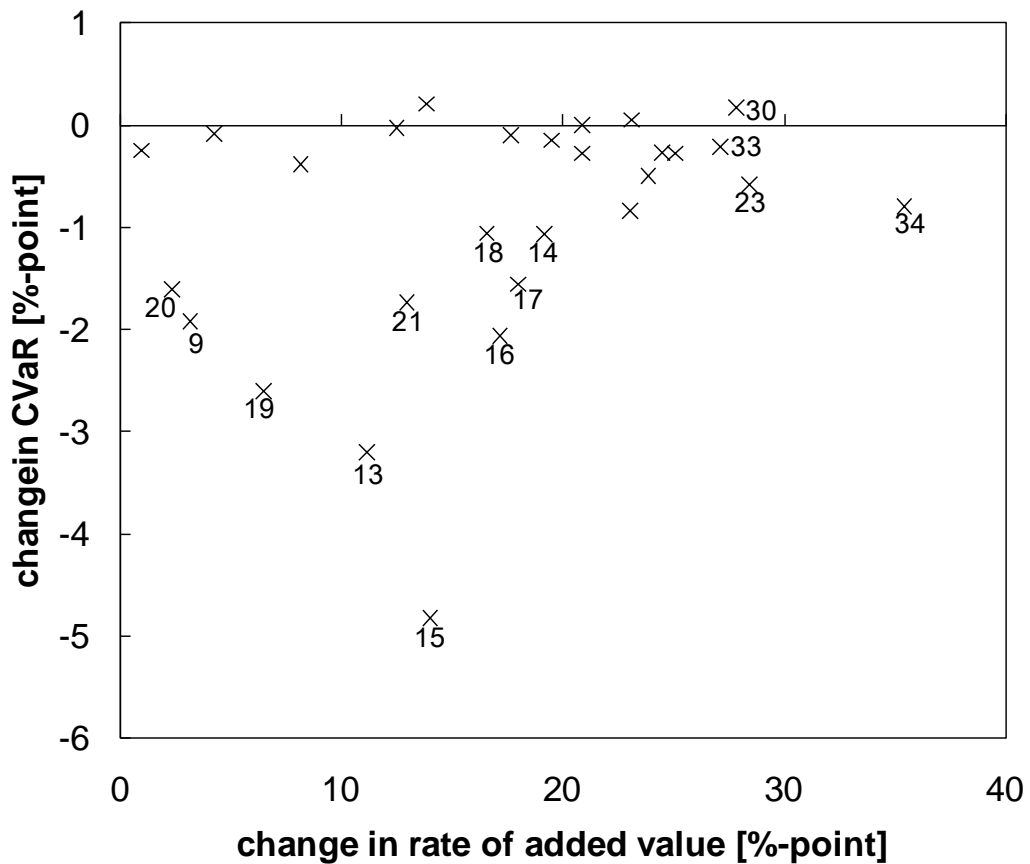


Figure 8. Relationship between the change in the rate of added value and the CVaR through the analysis period.

However, the increase in the added value varied among the manufacturing sectors with a similar degree of decrease in the CVaR.

This result indicates that an effort to decrease the risk is not always motivated by an economical profit. This tendency is especially strong in the service sectors consuming less energy for production than the manufacturing sectors. In fact, the improvements in Japan's energy usage has been strongly motivated by energy policies such as administrative

advice based on the Act on the Rational Use of Energy and taxation incentives to deploy appliances with high efficiency. To decrease the risk further, governmental regulations and incentives must play a significant role in the future.

4. Conclusion

This study proposes an analytical framework combining the I-O model and the portfolio approach based on the idea of a probabilistic I-O model, and estimates the risk of increase in the producer prices in the non-energy sectors by considering both the overall structure of Japanese industry and uncertainty in the price of imported fossil fuels. The non-energy sectors in Japan are analyzed during the period 1970–2000, and the cause of a reduction in risk is clarified by decomposing the risk index of each sector.

A reduction of risk in Japanese non-energy sectors has depended on the improvement in energy usage in a portion of these sectors, such as the coal products, chemical products, and steel sector. To decrease the risk further, these improvements are also required in other sectors.

Measures in the oil products sector are the most important because this sector is located upstream of all the non-energy sectors in the hierarchical structure. The growth of added value seems to be a basic measure in decreasing the risk in this sector. For this purpose, heavy oil fraction needs to be reformed to productions with higher added value such as gasoline or hydrogen. Reformation to hydrogen can contribute to the “hydrogen society” of the future. The sectors that directly consuming oil products, such as the agriculture and transport sectors, need to decrease their own energy consumption to decrease their risk. In the agriculture sector, the heat source for greenhouse, such as oil products, needs to be replaced with other types of energy, such as electricity or town gas. In the transport sector, the risk can be decreased as hybrid and fully electric cars are deployed. In the other sectors, replacing fossil fuel with non-fossil fuel in the electricity sector, increasing the share of electricity, and the replacement of oil products in the non-energy sectors need to continue and expand. When encouraging such measures, we need to remember that the measures taken in upstream sectors are much more effective than that in downstream sectors because of their indirect influence. Furthermore, proper policies or

regulations are required to improve such measures because these measures are not necessarily beneficial for the non-energy sectors, especially for service sectors.

The modeling of the prices in fossil fuels can be developed in the future work. This study assumes that the price in fossil fuels can be modeled by GBM. We think that this assumption is enough for this study because GBM model could successfully express the brief character of fossil fuel market: the price of crude oil has the largest average and volatility, the price of coal has the smallest average and volatility, and because this study focuses on the domestic industrial structure rather than international market structures. However, GBM may not be a best modeling of the price of fossil fuels. The selection of the price model need to be discussed in the future works.

The method proposed by this study can be applied to clarify the difference in the price risk and its causes among countries. The method can also focus on the national difference in the industrial structure by using I-O tables of several countries. Implications to decrease the risk of developing

countries will be obtained by comparing the industrial structure of developed and developing countries.

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Footnotes

1. There are also some studies analyzing the impact of an energy cost increase on countries other than Japan by applying the Leontief price model, such as Berument and Taşçi (2002), Han et al. (2004), Llop and Pié (2008) and Yoo and Yoo (2009).

2. The portfolio approach is also applied to energy-economics analyses on countries other than Japan. These studies include an analysis of the past and present energy mix (Bar-Lev and Katz, 1976; Humphreys and McClain, 1998) and import mix (Wu et al., 2009), an electricity planning study (Awerbuch and Berger, 2003; Awerbuch, 2006), an optimization of investments in the energy sector study (Fortin et al., 2008; Huang and Wu, 2008; Roques et al., 2008; Muñoz et al., 2009), and a risk management in electricity markets study (Liu and Wu, 2007; Yu, 2007; Bartelj et al., 2009; Deng and Xu, 2009). Various types of portfolio analysis are well documented in Bazilian and Roques (2008).

3. Santos et al. (2008) denote it as “conditional expected value,” but we denote it as “conditional value at risk (CVaR)” following other recent portfolio studies such as Fortin et al. (2008) or Bartelj et al. (2009).

4. Artzner et al. (1997) list characteristics that a risk index should satisfy: monotonicity, subadditivity, positive homogeneity, and translation invariance. They name risk indices satisfying all of them a “coherent risk measure,” and propose CVaR as one of the coherent risk measures.

5. We estimated the result for $\beta = 95\%$ and 97% , but there is no difference that changes the results of the analysis and the conclusion.