Quantifying energy price risk of Japan by applying I–O portfolio analysis

March 2011

Kengo Suzuki

Quantifying energy price risk of Japan by applying I–O portfolio analysis

Graduate School of Systems and Information Engineering

University of Tsukuba

March 2011

Kengo Suzuki

Abstract

The energy price risk is one of the largest barriers preventing the stable supply of energy in Japan. The energy price risk is defined as the risk of increase in the prices of domestic products caused by an increase in the prices of energies. The energy price risk of Japan needs to be analyzed by four reasons: increasing energy demand, heavily relying on imported fossil fuels, fluctuating market prices of fossil fuels, and emerging discussion to tax greenhouse gases emissions. Japan has implemented various policies to mitigate the energy price risk since the two oil crises happened in the 1970s. To analyze the impacts of those policies on the energy price risk, following four factors need to be endogenized: difference in uncertainty among the prices of each type of fossil fuels, primary energy selection by the energy conversion sectors, final energy selection by the non-energy sectors, and indirect energy consumption relying on a national industrial structure. Although the first and second points of views were investigated in many earlier studies, the third and fourth ones were not.

The purpose of this dissertation is to quantify the change in the energy price risk of all sectors in Japan to clarify the cause of change in the energy price risk, and to obtain implications for future energy policy. For the purpose, this dissertation proposes new analytical framework that can endogenize on all the four factors above.

Before proposing the new analytical framework, this dissertation introduces the conventional portfolio analysis that endogenizes the first and second factors in Chapter 2. The chapter consists of the review and application of the portfolio analysis. By applying the portfolio analysis, the contribution of diversified fossil fuel sources on the price risk of direct energy consumers in Japan is analyzed. There are three major findings from the preliminary analyses in this chapter. First, an index of the energy price risk needs to focus on only the price deviation above the expected value. By the reason, the portfolio upper semivariance is the better measure of the risk than the portfolio variance. Second, not only crude oil but also other types of fossil fuels need to be included in the portfolio analysis. Third, the electricity generation sector reduced the risk caused by an individual import source of fossil fuels, but failed to decrease the risk caused by correlations among the prices of import sources. Since the correlation among the prices of the same types of fossil fuels are more strongly correlated than the prices of different types of fossil fuels, the portfolio diversification among the different types of fossil fuels needs to be given a preference than that among the different imported countries.

However, the conventional portfolio method cannot endogenize final energy

selection by the non-energy sectors and indirect energy consumption relying on a national industrial structure. Both the problems are caused by the ignorance of interrelationship among the domestic sectors. There are two types of energy price risk: direct and indirect energy price risk. The former arises from consuming primary energy, and the latter arises from consuming final energy and non-energy products. In order to quantify both the risks, overall input-output structure should be endogenized to the model because the amount of indirect influence is determined by the structure of various production chains.

For the purpose, this dissertation proposes a new analytical framework, input–output (I–O) portfolio analysis, and estimates the risk of increase in the producer price of domestic sectors in Chapter 3. This analytical framework is based on all the four factors presented above. The I–O portfolio analysis consists of three steps: Monte Carlo simulation, calculation of the risk index, and decomposition of the risk index. The Monte Carlo simulation consists of three steps. First, yearly change in the prices of fossil fuels and CO_2 are estimated using the geometric Brownian motion (GBM) model. Second, the producer prices of domestic sectors are estimated by applying the Leontief price model. Third, increases in the total expenditure of the final consumption sectors, such as the household and government sectors, are estimated. As the result of the Monte Carlo simulation, probabilistic density functions of the change in the producer prices and total expenditures of domestic sectors are obtained. Next, the conditional value at risk (CVaR) in those changes can be estimated from probabilistic density functions. Finally, the CVaRs are decomposed into direct and indirect input factors of each types of energy. In addition to the introduction of analytical framework, the number of iterations required to one set of Monte Carlo simulation is determined by estimating the error in simulations. The results indicate that 100,000 iterations are required to keep the size of error around 3% if the confidence level of CVaR is set to 95%.

In chapter 4, the short-term portfolio selection by the electricity generation sector is examined if such a selection can decrease the risk of energy cost volatility in the energy and non-energy sectors, considering uncertainty in both energy and CO_2 prices. The short-term portfolio selection indicates a change in the generation mix under the restrictions of existing capacities. The I−O portfolio analysis is revised for this purpose; the generalized minimum cost flow (GMCF) model is newly introduced to take the change in the generation mix in response to the energy and CO_2 prices into consideration. The four scenarios with different CO_2 price levels are prepared to clarify an influence of the level of CO_2 price on the energy price risk. The results indicate that the energy cost of the industrial sector is more affected by that of the commerce and household (C&R) sector because the share of coal in the industrial sector is larger than that in the C&R sector. Then, we need to endogenize the energy mix of non-energy sectors when we quantify the energy price risk of those sectors. When the CO_2 cost is imposed to the electricity generation sector, the energy price risk of the electricity generation and C&R sectors can be compensated by changing the generation mix if the levels of value and volatility in the CO_2 market are equal to those in the European Climate Exchange (ECX) market, but the risk of the industrial sector cannot be compensated because the sector consumes more coal and coal products than the electricity generation and C&R sectors. If the levels of value and volatility in the CO_2 market become higher than the present status, the change in the generation mix cannot compensate an increase in the risk, and the long-term portfolio selection such as change in the generating facility mix is also required to decrease the risk further.

In Chapter 5, the energy price risk of non-energy sectors is estimated during the period 1970–2000 by applying the I–O portfolio analysis. The causes of risk reduction through the analysis period are clarified by decomposing the risk index into the constituent parts of direct and indirect inputs of fossil fuels as well as final energies. In addition, the relationship among the changes in the energy price risk, the energy cost per unit production, and the rate of added value are analyzed. The results indicate that almost all sectors decreased their CVaR through the analysis period. The reduction of the risk in the non-energy sectors are depended on the improvement of energy usage in a portion of sectors, such as the coal products, chemical products, and steel sector. To decrease the risk further, such improvements are also required in other sectors. Measures in the oil products sector, e.g. substituting the share of heavy oil with hydrogen by upgrading refinery infrastructure, are the most important to decrease the risk because this sector uses the fossil fuel with the highest price risk as the main material of their production. The sectors directly consuming oil products, such as the agriculture and transport sectors, also 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 be continued and expanded. When encouraging such measures, policy makers 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 those measures are not necessarily beneficial for the non-energy sectors, especially for the service sectors.

In Chapter 6, the energy price risk of the household sector is estimated during the period 1995–2005 by applying the I–O portfolio analysis. While the analysis in the previous chapter uses conventional monetary based I–O tables, we develop hybrid-unit I–O tables, which represent the energy inputs in energy units and non-energy inputs in monetary units. The results indicate that the energy price risk of the household sector has decreased through the analysis period in spite of increasing energy consumption. There are three types of changes in the consumption pattern of the household sector, which play an important role in the changes in the risk: development in energy use, electrification, and a trend toward a service economy. The risk of the electricity generation, chemical products, and road freight transport sectors were decreased by increasing energy intensity and substituting oil with other energy sources. Since the risk of electricity generation is decreased, the electrification of the household sector can decrease its own energy price risk. The trend to a service economy includes an increase in the share of sectors with smaller energy price risks, such as electric machines, communication and broadcasting services, and medical and social security sectors. Since the risk of those sectors is smaller than those in primary and secondary industries, the trend to service economy can decrease the energy price risk of the household sector.

In conclusion, the I–O portfolio analysis succeeds in explaining a relationship between changes in the energy price risk and domestic industrial structure by applying the single analytical framework. The method enables us to compare the energy price risk of different sectors in a single economy, and the same sector in different economies and different time periods. Such a comparison enables us to learn from practical cases in the past and in the other countries, and to transmit the analytical results of succeeded cases to developing countries and regions. The method also presents some new implications from results such as an importance of energy substitution in the agriculture sector and the trend to a service economy. Further, this analytical framework can take not only economical but also technological change in the domestic sectors into consideration. For example, in the case of the electricity generation sector, uncertainty in the prices of fossil fuels and CO_2, the change in the generation mix, and the development of energy efficiency in plants can be analyzed on a single analytical framework. On the other hand, the GBM model adapted by the I–O portfolio analysis is not a perfect emulation of actual changes in the prices of fossil fuels and CO_2: the actual price distribution has longer upper tail than that of the GBM. Such a problem can be solved by developing the method that can estimate long-term characteristics from short-term data.

Based on those discussions, the three directions of future developments can be proposed from this dissertation. The first is the detailed analysis of domestic sectors whose energy price risk has not decreased through the decades. Especially, the agricultural sector in Japan is heavily reliant on oil products nevertheless the sector is focused on as one of the drivers of Japanese economy in the future. Then, the present status of energy price risk in the sector need to be clarified in detail, and the risk reduction effect of substituting oil products with other type of energy needs to be analyzed. The smaller scale and more regional versions of the I–O portfolio analysis can contribute to the purpose. The second is the comparison of sectoral energy price risk among different nations and regions. By clarifying the difference of the risk level and causes of the risk, policies required for the nations and regions can be found. Because almost all sectors in Japan succeeded in reducing the risk through the decades, the structural changes in the past can be the benchmark for newly developing countries. On the other hand, the difference of energy price risk among regions in Japan is not clarified in this dissertation. Since climatic condition varies among the regions in Japan, the difference of risk among the regions needs to be recognized before making optimal energy policies for each region. The third is to develop the modeling of energy price uncertainty. As discussed above, if the long-term characteristics of energy and CO_2 markets are estimated from the short-term characteristics of them, the long-term analysis of the energy price risk can derive more accurate results. And such a method can contribute to not only the I–O portfolio analysis but also other types of method estimating the present and future energy price risk.

Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

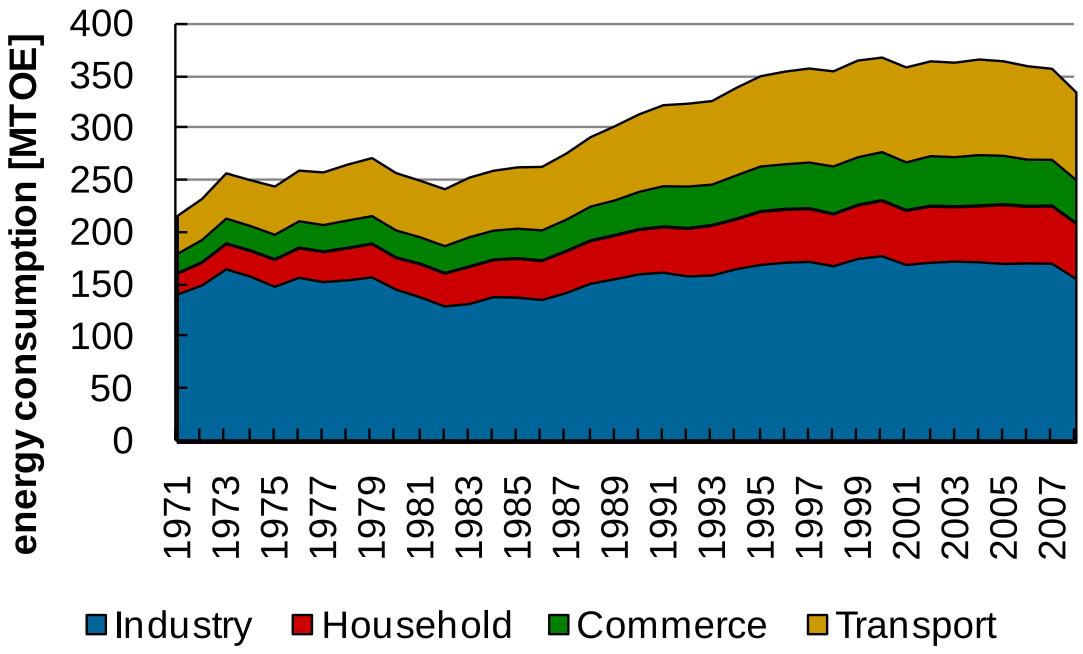
1.1. Energy Price Risk in Japan

The energy price risk is one of the largest barriers preventing the stable supply of energy in Japan. The energy price risk is defined as a risk of increase in the prices of domestic products caused by an increase in the prices of energies. The energy price risk of Japan needs to be analyzed by four reasons: increasing energy demand, heavy reliance on imported fossil fuels, fluctuating market prices of fossil fuels, and emerging discussion to tax greenhouse gases emissions.

First, domestic energy demand in Japan has increased during the period 1970– 2007 as presented in Figure 1.1; the demand is mainly increased in non-industrial sectors, such as the household, commerce, and transport sectors. Such an increase in the energy demand is resulted from the modernization of the society including deployment of automobile, just-in-time transportation, the information technologies, overnight shops, and new types of home appliances. In addition to the deployment of those goods and services, an increase in the number of households also plays an important role for increasing the energy consumption per capita. Economic impact of an increase in the price of energy becomes large as the domestic energy demand increases.

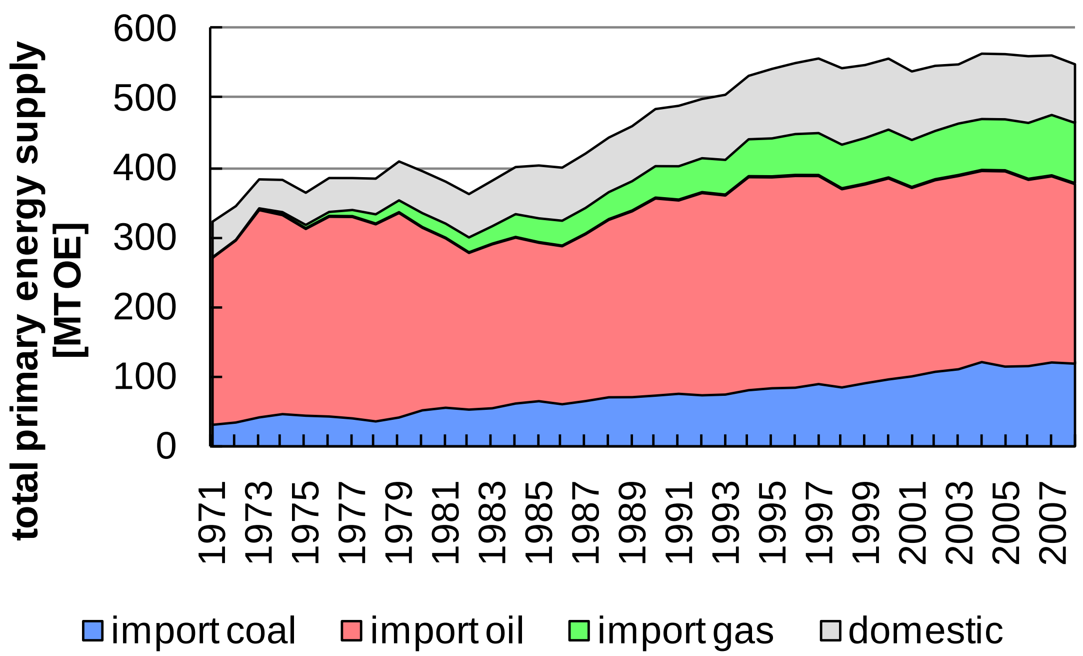
Second, Japan is heavily reliant on imported fossil fuels to satisfy the energy demand. Figure 1.2 presents the breakout of total primary energy supply in Japan. The volume of imported oil has not decreased from the 1970s, and that of imported coal and natural gas have increased as the total primary energy supply increases. As the energy demand increase, Japan needs to import more fossil fuels because of few fossil fuel reserves, few candidate sites for nuclear plants accepted by citizens, and much more expensive cost for renewable energies than fossil fuels. Figure 1.2 indicates that Japan has continued relying on imported crude oil, and has become to rely more on other types of imported fossil fuels, such as coal and natural gas. This high dependency on the imported fossil fuels also increases the energy price risk.

Third, the prices of fossil fuels are fluctuating in international markets during the latest decade. Figure 1.3 presents the change in the prices of coal, crude oil, and natural gas in various regions. The crude oil has the highest price risk among the fossil fuels because of its largest volatility. One of the largest causes of this volatility is



Source: EDMC Handbook of Energy & Economic database [01]

Figure 1.1 Breakout of final energy consumption in Japan.



Source: EDMC Handbook of Energy & Economic database [01]

Figure 1.2 Breakout of total primary energy supply in Japan.

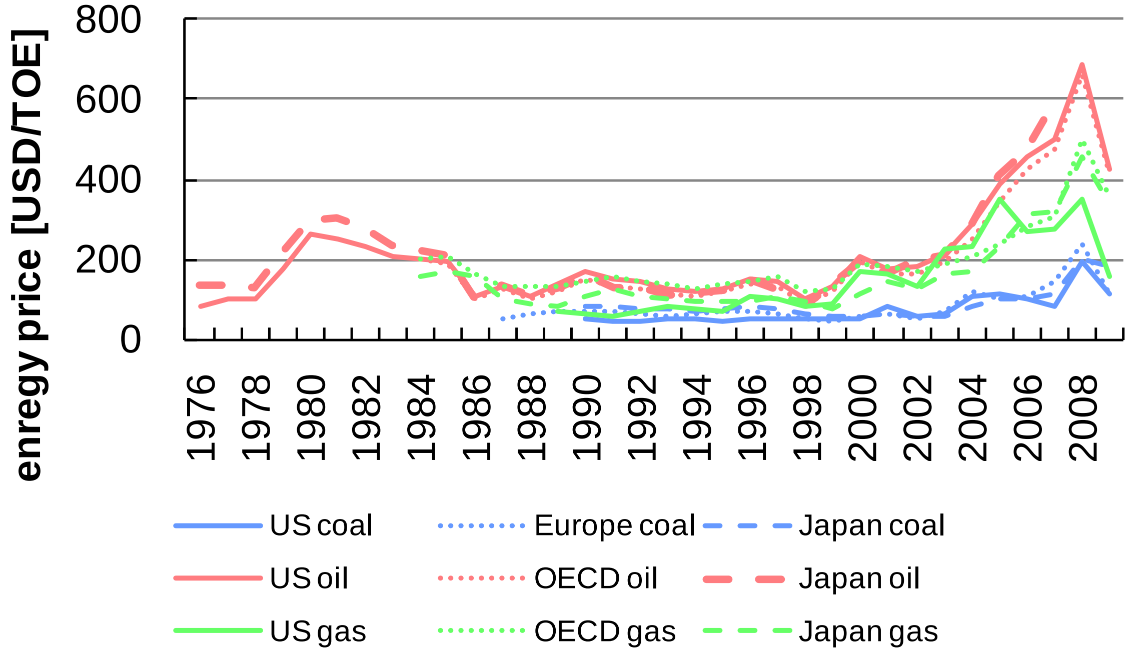
an increasing demand, especially in Asian countries. As presented in Figure 1.4, the demand for crude oil is mainly increased in Asian countries, such as China and India. In addition, the deregulation and internationalization of the oil market brought a new type of uncertainty, i.e., the financial risk. While the energy derivatives can increase the transparency and liquidity of the oil market, it also increases the volatility in the market [02]. Further, it is pointed out that the large amount of long positions held by the unskilled players in the market, such as institutional investors and Sovereign Wealth Funds (SWF), have influenced an increase in the price of crude oil in the late 2000s [03].

Fourth, consumers of fossil fuels will be required to pay additional tax for emitting greenhouse gases if countermeasures against global warming, such as the emissions trading system (ETS) and carbon taxes, are introduced. Especially, The ETS brings new cause of energy price risk, i.e. market risk, because the ETS is based on the price formation of CO_2 in open markets such as European Climate Exchange (ECX). For Japan, the ETS has been experimentally introduced [05], and Ministry of the Environment (MOE) is trying to officially introduce the ETS until 2013.

Japan has implemented various policies to mitigate the energy price risk after the two oil crises in the 1970s. First, the Oil Substitution Act is enacted to decrease the share of crude oil in the primary energy supply in 1980. The government is required to set up a guideline for energy consumers to introduce substitutional energy, and energy consumers are required to make efforts to keep the guideline. Further, New Energy and Industrial Technology Development Organization (NEDO) is established for the research and development of substitutional energy technologies to serve the purpose of the act. Second, the Three Power Source Siting Laws are enacted to subsidize the regions accepted power plants, upgrade social infrastructures in the regions, and tax energy consumers for financial source of the subsidy in 1974. Nuclear power plants would have not been deployed without the laws because they are usually built far from the points of demand, and bring little benefit to the points of supply. Third, Act on The Rational Use of Energy is enacted to save the domestic energy consumption in 1979. At first, the act targeted large factories, buildings, and machines, and required energy saving of them. Later, the act became to target transport sectors, buildings, appliances, and commerce sectors as the global warming problem emerges and the prices of fossil fuels increase[1,2].

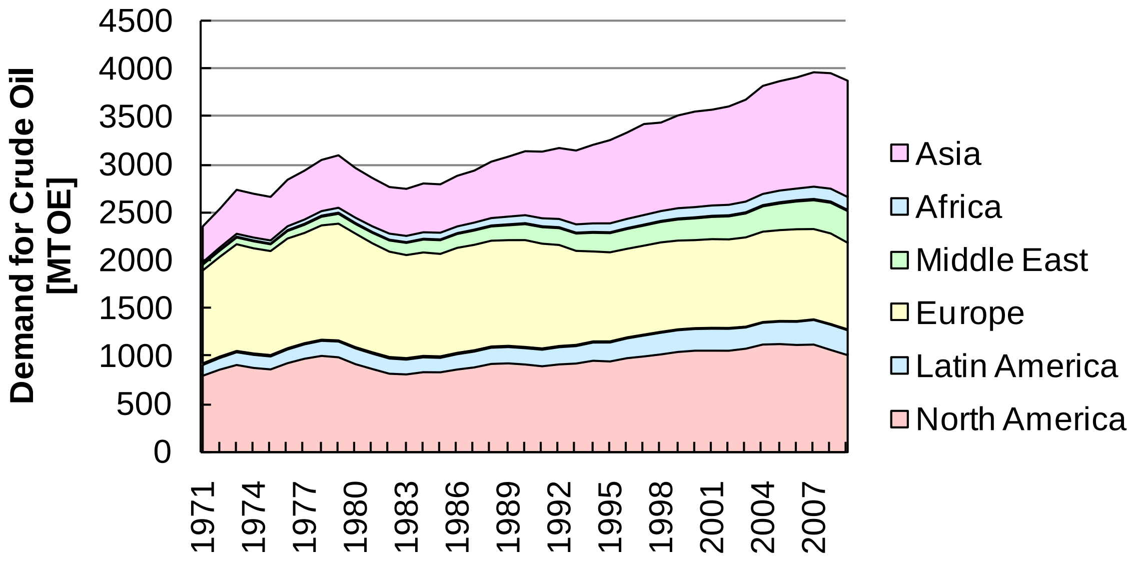
[1] In addition to those acts, Oil Stockpiling Act is enacted to make ready to the disruption of oil import. This act obliges the government and oil companies to stock the determined volume of crude oil and oil product, and provide some financial to the companies. Although the act does not decrease the energy price risk, it also contributes to enhance the energy security of Japan.

[2] Whole texts of the energy policies explained here can be confirmed at the website of Japanese



Source: EDMC Handbook of Energy & Economic database [01] and BP statistical review of world energy 2010 [04]

Figure1.3 Prices of coal, oil and natural gas in various regions.



Source: BP statistical review of world energy 2010 [04]

Figure1.4 Share of demand for crude oil in the world.

government [06] [07].

To analyze the impacts of those policies on the energy price risk, following four factors need to be endogenized: difference in uncertainty among the prices of each type of fossil fuels, primary energy selection by the energy conversion sectors, final energy selection by the non-energy sectors, and indirect energy consumption relying on a national industrial structure. First, a risk of price fluctuation in fossil fuel markets varies among different types of fossil fuels. For example, the price of West Texas Intermediate (WTI) crude oil, which is used as one of the benchmark prices in the worldwide market, fluctuates much larger than the price of coal spot market in U.S. as shown in Figure 1.3. Then, the contribution of oil substitution on mitigating the energy price risk cannot be analyzed without endogenizing the difference in the uncertainty among the prices of fossil fuels into analytical framework. Second, primary energy selection by energy conversion sectors affects the energy price risk of whole the nation. If the energy conversion sectors are heavily reliant on crude oil, not only themselves but also consumers of their productions are suffered from high energy price risk. Then, the change in the primary energy selection of energy conversion sectors needs to be considered. Especially, that of the electricity generation sector is important because the demand for electricity is increasing in Japan and the electricity generation has a potential to change energy mix. Third, final energy selection by the non-energy sectors also affects the energy price risk of whole the nation. A risk of price fluctuation in the fuel oil is higher than that in electricity because the former is made of crude oil whose import price fluctuates hard, and the latter include nonfossil primary energies in their materials. Then, the change in the final energy selection of the non-energy sectors affects the energy price risk of themselves and customers of them. Fourth, the change in the industrial structure needs to be endogenized because many sectors indirectly consume energy via production chains of goods and services that are directly consumed by those sectors. For example, the civil engineering sector indirectly consumes a lot of coal because the sector directly consumes cement and steel sectors. This point of view is important when analyzing the energy price risk of non-energy sectors because they have complex interdependency through input and output of their products.

Although the first and second points of views were endogenized into the analytical frameworks of many earlier studies, the third and fourth were not. Many statistic models have been proposed to describe the uncertainty in the prices of fossil fuels. Those models include Geometric Brownian Motion (GBM) model, Mean Reverting (MR) model, multivariate Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model, and multifractal detrended fluctuation analysis (MF-DFA). Portfolio analysis has been applied to quantify the energy price risk of a nation or an energy conversion sector endogenizing both the uncertainty in the price of primary energies and the selection of energy conversion sectors. However, the final energy selection of non-energy sectors and the domestic industrial structure have not been considered when analyzing the domestic energy price risk. While there are some earlier studies analyzing the impact of an increase in the price of fossil fuels on a domestic economy, almost all of them focus on macroeconomic aspects of the impact, such as the impact on GDP and employment, and do not focus on the energy price risk in sector-scale, which is important to clarify the cause of success and failure of policies and efforts, and to obtain policy implications which sectors require further measures against energy price risk. Above all, there is no study analyzing the energy price risk endogenizing all the four factors listed above.

1.2. Purpose and Outline of Dissertation

The purpose of this dissertation is to quantify the change in the energy price risk of domestic sectors in Japan to clarify the cause of change in the energy price risk, and to obtain implications for future energy policies. For the purpose, this dissertation proposes a new analytical framework that can endogenize all the four factors presented in the previous section. This dissertation consists of seven chapters including this chapter, Chapter 1.

In the Chapter 2, the standard portfolio analysis is introduced. The standard portfolio analysis can endogenize the two of four factors: difference in the uncertainty among the prices of each type of fossil fuels, and primary energy selection by energy conversion sectors. The chapter consists of three contents: reviewing earlier studies, clarifying the contribution of the diversified import sources of crude oil on the price risk for all the energy consumers, and clarifying contribution of the diversified import sources of fossil fuels on the price risk for the electricity generation sector in Japan. The contents of this chapter are based on publications [J1], [J3], and [C2].

In Chapter 3, a new analytical framework, input–output (I–O) portfolio analysis, is proposed. The I–O analysis is combined with the portfolio analysis to endogenize the third and fourth factors presented in the previous section: final energy selection by non-energy sectors, and indirect energy consumption relying on national industrial structure. This chapter also explains how to define the index of the energy price risk derived from whole the factors explained above, and how to decompose the index of the risk into the factors of the risk. The contents of this chapter are based on publication [J2].

In Chapter 4, the influence of the cost for CO_2 emission on the energy price risk is clarified. The role of change in the electricity generation mix on the risk is also clarified under the restrictions of existing generation facilities and the uncertainty in the prices of imported fossil fuels and CO_2 emission. Only a portion of the analytical method proposed in the previous chapter is utilized here because I would like to focus on the electricity generation sector rather than non-energy sector. Instead, the portfolio selection of the electricity generation sector is modeled by combining the network flow model and Leontief price model. The contents of this chapter are based on publications [J4] and [C1].

In the Chapter 5, a risk of increase in the producer price of the non-energy sectors is estimated during the period 1970–2000. The change in the prices of imported coal, crude oil, and natural gas are assumed to the causes of the energy price risk in those sectors. The study in this chapter focuses on the industry, commerce, and transport sectors; the household sector is focused on in the next chapter. The causes of the 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 conditional value at risk (CVaR), the energy cost per unit production, and the rate of added value are analyzed. Some implications are derived from the results of those analyses. The contents of this chapter are based on publication [J2].

In the Chapter 6, the energy price risk of the household sector is estimated. While the analysis in the previous chapter used conventional monetary based I–O tables, we develop hybrid-unit I–O tables, which represent energy inputs in energy units and the non-energy inputs in monetary units, during the period 1995–2005. In addition to the three types of fossil fuels endogenized into the analytical framework in the previous chapter, additional three types of fossil fuels, i.e. naphtha, liquefied petroleum gas (LPG), and heavy oil, are newly endogenized into the analytical framework as the causes of the energy price risk. The contents of this chapter are based on publication [J5].

In the Chapter 7, some conclusions are presented.

Chapter 2

Theory and Application of Portfolio Analysis

In this chapter, the standard portfolio analysis, which analyzes the energy price risk endogenizing a difference in uncertainty among the prices of fossil fuels and the primary energy selection of energy sectors, is introduced. Further, the method is applied to the preliminary analyses for the I–O portfolio analysis. This chapter consists of three contents: reviewing earlier studies, clarifying contribution of the diversified import sources of crude oil on the energy price risk of all energy consumers in Japan, and clarifying the contribution of diversified import sources of fossil fuels on the energy price risk of the electricity generation sector in Japan.

2.1. Literature Review

The energy portfolio of a consumer, the share of each type of energy in the total energy consumption, can affect the energy price risk. The portfolio analysis [08] has been applied to analyze the relationship between the energy portfolio and energy price risk. According to the method, the energy price risk of a consumer depends on three factors: price volatility in each energy market included in the portfolio, price correlations among the energy markets, and the share of each energy market [09]. The portfolio analysis can quantify the energy price risk by endogenizing all the three factors.

The portfolio analysis firstly applied to analyze the past and present energy mix or import mix to obtain some implications. Bar-Lev and Katz [10] analyzed the fossil mix of the US electric utility sector and demonstrates that the sector tends to take high risks to save costs. Humphreys and McClain [11] found that the fossil fuel mix of the US electric utility sector roughly minimized the energy price risk in the 1980s; they also observe the share of natural gas being increased in the 1990s as natural gas allows for higher returns by taking high risk. Lesbirel [12] applied the simplified portfolio model [13] to analyze the fossil fuel mix in Japan. The result indicates that the energy price risk of Japan has decreased in the 1990s even though 80% of the country's fossil fuels are imported from specific regions. Hattori [14] presented 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. Wu et al. [15] analyzed the import mix of crude oil in China, and found that the energy price risk of

China can be decreased by leveling the monthly deviation of the import quantity and increase the share of import from Russia.

The developed portfolio analysis become to be applied to a risk management in the electricity market as the deregulation of the electricity market develops. Liu and Wu [16] and Yu [17] proposed the method to estimate the optimal selection, i.e. the selection of customers maximizing the profit, for electricity generation companies, and Bartelj et al. [18] proposed the method for the retail companies. Deng and Xu [19] clarified the efficacy of Demand Response (DR) program, which can change in electricity usage by consumers from their normal consumption patterns in response to changes in the electricity price over time, to decrease the energy price risk.

Further, the portfolio analysis is applied to the field of planning investments against generating facilities. Awerbuch and Berger [20] analyzed a present and projected fuel mix in the EU electricity generation sector. The result indicates that the energy price risk of the sector can be decreased by increasing the share of wind power. Similar analyses have been performed on the electric utility sector of Netherlands [21], Taiwan [22], and U.S. [23]. All of those studies indicate that the energy price risk can be decreased by increasing the share of renewable energy. Fortin et al. [24] proposes the method combining the portfolio analysis and real option analysis that can select the investment portfolio to energy plants maximizing the profit of investors. The result indicates that the portfolio diversification from coal to renewable is preferred by investors even in the case with low CO_2 price. Roques et al. [25] analyzed the optimal selection of power plants maximizing the profit by endogenizing both the cost for power generation and CO_2 emission into the analytical framework. The result clarifies the reason why the share of combined cycle gas turbine in the U.K. generation mix increases; the strong positive correlation between the gas and electricity prices decreases the risk of building the CCGT.

2.2. Portfolio of Crude Oil in Japan

2.2.1. Motivation

This dissertation starts from analyzing Japanese energy portfolio by applying the standard portfolio analysis because there are few studies analyzing time series change in Japanese energy price risk. As presented in the Chapter 1, the volume of imported crude oil has not decreased during the period 1971 to 2008, and is still the largest among that of all types of primary energy. On the other hand, Japan has tried to diversify the import source of crude oil to enhance the energy supply security [26].

While some earlier studies analyzed the energy portfolio of Japan [12] [14], they did not clarify the time series change in the energy price risk. While Yuasa and Uchiyama [27] analyzed the time series changes in the volatility of imported quantity and value, especially the changes triggered by the political incidents such as a war and a production adjustment, they did not analyze the energy price risk.

2.2.2. Portfolio Analysis

The portfolio analysis can estimate the optimal portfolio, i.e. the import portfolio minimizing the energy price risk, from the time series data on the price of energy in each import source and the share of each import source. Any portfolio can be presented by a vector whose elements are the shares of each import source as

$$X=(x_1, x_2, \ldots, x_N) \tag{2-1}$$

where x_i indicates the share of import source i. Markowitz [08] defined two indices measuring the performance of a portfolio: the portfolio return and portfolio variance as

$$r_p = \sum_{i=1}^{N} r_i x_i \tag{2-2}$$

$$\sigma_p^2 = \sum_{i=1}^{N} \sum_{j=1}^{N} x_i x_j \sigma_{ij} \tag{2-3}$$

where r_i indicates the expected inverse price of import source i, N is the number of import sources, and σ_{ij} indicates the covariance between inverse prices of import source i and j; $\sigma_{ij} = \sigma_i^2$ when $i = j$.

Sharpe [28] defines the price risk of a portfolio as

$$s = \sigma_p / r_p \tag{2-4}$$

because the risk can be affected by both the portfolio return and portfolio variances. This index of price risk is generally called Sharp ratio. The portfolio minimizing Sharp ratio can be estimated by solving the quadratic programming problem

$$\min \quad s = \frac{\sqrt{\sum_{i=1}^{N}\sum_{j=1}^{N} x_i x_j \sigma_{ij}}}{\sum_{i=1}^{N} r_i x_i} \tag{2-5}$$

$$\text{s.t.} \quad \sum_{i=1}^{N} x_i = 1 \tag{2-6}$$

$$x_i \geq 0 \qquad i = \{1, \cdots N\}\,. \tag{2-7}$$

The constraint (2-6) indicates that the sum of the share needs to be one, and the constraint (2-7) indicates the prohibition of short selling. Before solving the problem, a fraction needs to be removed from the objective function. We define a vector $W = (w_1, w_2, \ldots, w_N)$ fulfilling

$$x_i = r_p w_i. \tag{2-8}$$

The quadratic programming problem (2-5) to (2-7) can be rewritten as

$$\min \quad \sqrt{\sum_{i=1}^{N}\sum_{j=1}^{N} w_i w_j \sigma_{ij}} \tag{2-9}$$

$$\text{s.t.} \quad \sum_{i=1}^{N} r_i w_i = 1 \tag{2-10}$$

$$w_i \geq 0 \qquad i = \{1, \cdots N\}\,, \tag{2-11}$$

and the optimal solution of the original problem, $X^* = (x^*_1, x^*_2, \ldots, x^*_N)$, is given as

$$x_i^* = w_i^* \Big/ \sum_{j=1}^{N} w_j^* \tag{2-12}$$

where $W^* = (w^*_1, w^*_2, \ldots, w^*_N)$ is the optimal solution of the modified problem (2-9) to (2-11).

2.2.3. Data and Results

The time series data on the price and the share of crude oil in each import source are obtained from Japan Exports & Imports [29] recording the quantity and value of crude oil imported to Japan every month. Those imported prices are CIF prices on a yen basis including changes in the exchange rate, the cost of transport, and insurance from supplying countries to Japan.

We choose eight terms for the analysis: five disputing terms with a war or a production adjustment, and three stable terms without such an incident. Those terms are chosen based on the Yuasa and Uchiyama [27], and the two latest terms are added by expanding data set. The length of each term is set to three years. We integrate all import sources into three regions: Asia, Middle East (ME), and other areas (Others). Table 2.1 presents the definition of each term, Table 2.2 presents the share in the actual portfolio, x_i, the expected value in the inverse price, r_i, and the standard deviation in the inverse price, σ_i, in each region. Table 2.3 presents the correlation coefficients among the regions.

Two results are obtained; the first result shows how the actual portfolio should be changed in order to decrease the energy price risk and the second result shows how much risk would have decreased if Japan chose the optimal portfolio compared with its actual portfolio selection. Those results are presented in Figure 2.1 and 2.2.

Figure 2.1 presents the differences between the share of import sources in the optimal and actual portfolio. The optimal portfolio X* is obtained by solving the problem (2-9)–(2-12), and the actual portfolio is presented in Table2.2. By substituting shares of each energy source in actual portfolio from that in optimal portfolio, the difference shows how the actual portfolio needs to be changed to minimize the energy price risk; the import sources with positive difference need to be increased, and those with negative difference need to be decreased. The difference in the share of import from Middle East takes negative value in all periods except for term 1. This result indicates an importance of substituting import from Middle East with other regions to decrease the risk. As presented in Table 2.2, the share of Middle East is much higher than that of other regions, and Japanese government has recognized the regional substitution of oil as one of the most important energy policy. However, the import share of Middle East has increased after the second stable term, and Japanese portfolio of oil supply has not been changed toward the optimal portfolio.

On the other hand, Figure 2.2 presents the Sharpe ratio for the optimal and actual portfolio in each term. The energy price risk becomes higher in the disputing terms than the stable terms. However, the Gulf War term is the exception; the risk did not increase in the term. The influence of the Gulf War was smaller than other

Table 2.1 Definition of eight terms: five disputing terms (term 2, 3, 5, 7, 8) and three stable terms (term 1, 4, 6).

term No.	term name	period
1	Stable1	1970.1–1972.12
2	Yom Kippur War	1973.10–1976.9
3	Iranian Revolution	1979.2–1982.1
4	Stable2	1987.1–1989.12
5	Gulf War	1990.8–1993.7
6	Stable3	1995.1–1997.12
7	OPEC production adjustment	1999.2–2002.1
8	Iraq War	2003.4–2006.3

Table 2.2 Share in the actual portfolio, the expected value in the inverse price, r_i, and the standard deviation in the inverse price, σ_i, in each region.

term	import share [%]			expected value [kl/¥]			standard deviation [kl/¥]		
No.	Asia	ME	Others	Asia	ME	Others	Asia	ME	Others
1	14.5	83.7	1.9	0.0761	0.0907	0.0661	0.0083	0.0057	0.008
2	19.9	76.9	3.2	0.0284	0.0338	0.0274	0.0084	0.0145	0.009
3	24.2	72.6	3.2	0.0198	0.0203	0.0177	0.0064	0.0068	0.005
4	25.1	68.7	6.2	0.0644	0.0681	0.0698	0.001	0.0122	0.0131
5	21.8	73.7	4.4	0.0608	0.0651	0.0619	0.0102	0.012	0.0105
6	16.2	80.5	3.3	0.0774	0.0798	0.0582	0.0139	0.0143	0.014
7	9.6	86.8	3.6	0.0599	0.0626	0.0611	0.0184	0.0194	0.0208
8	5.5	89.2	5.3	0.0336	0.0361	0.033	0.0084	0.0089	0.0081

Table 2.3 Correlation coefficients among the regions.

term No.	Asia-ME	Asia-Others	ME-Others
1	0.453	0.394	0.58
2	0.988	0.962	0.955
3	0.997	0.895	0.885
4	0.982	0.977	0.976
5	0.97	0.962	0.969
6	0.987	0.978	0.98
7	0.993	0.955	0.944
8	0.984	0.99	0.982

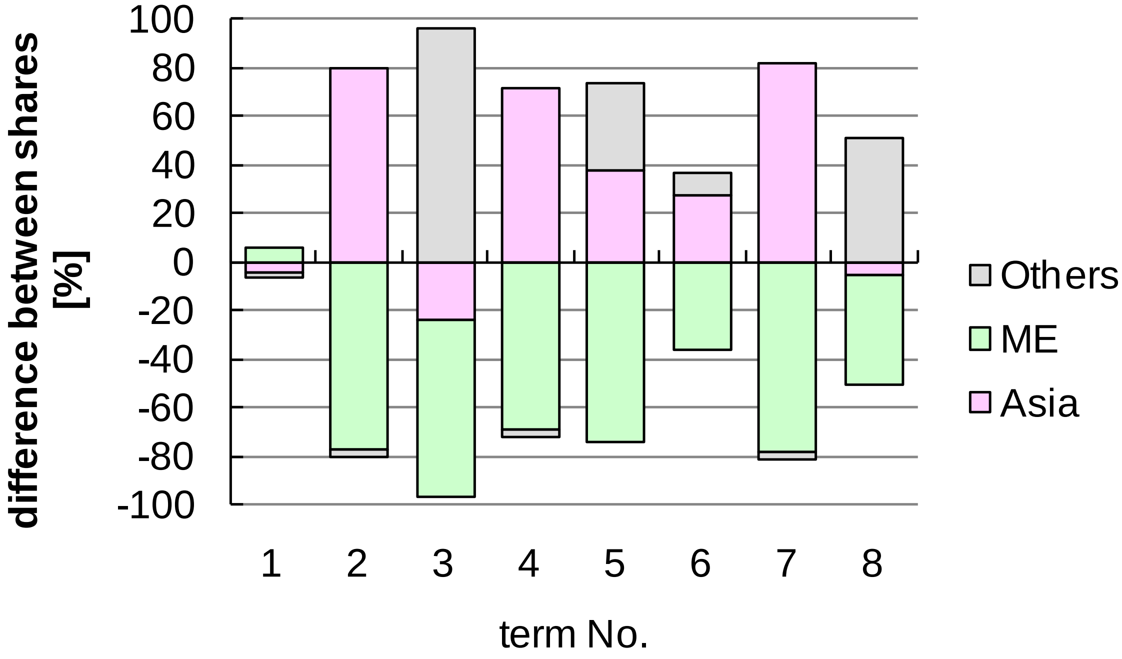


Figure 2.1 Differences in the share of import sources between the optimal and actual portfolio of crude oil in Japan.

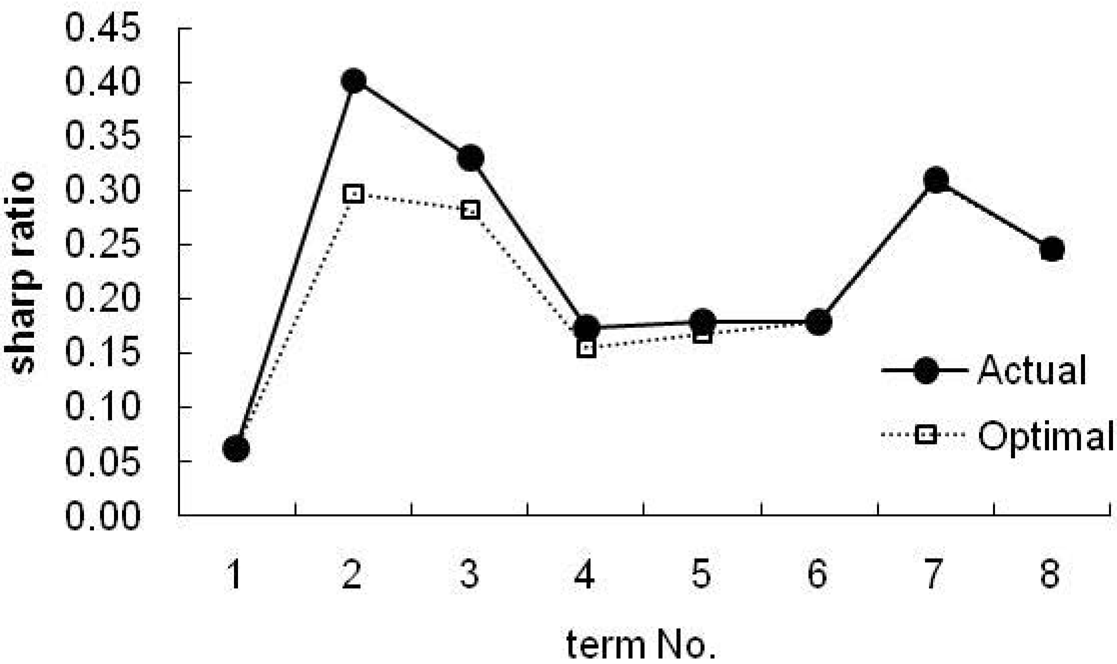


Figure 2.2 Time series change in the Sharpe ratio of the optimal and actual portfolio.

incidents because the war continues less than two months. Another finding from the Figure 2.2 is that the difference between the Sharpe ratio in the optimal and actual portfolio is getting smaller through the analysis period. This change indicates that the diversification of import source becomes less important to decrease the energy price risk because the Sharpe ratio cannot be decreased even if the shares of import sources are optimized. Two causes can be considered: the intention of correlations and the equalization of standard deviations among the prices of import sources. The former is not the cause because the correlations coefficients among the prices of import sources have seldom changed through the analysis period; they are nearly one even in the Yom Kippur War term as presented Table 2.3. On the other hand, the difference among the standard deviations became smaller after the Yom Kippur War term, and those in three regions becomes nearly the same value in the third stable term. Then, the decrease in the importance of the diversification of the import sources is caused by the equalization of standard deviations among the prices of import sources. The equalization is caused by the internationalization of crude oil market, and indicates the rapid propagation of a price shock in one region to other regions.

2.3. Portfolio of Fossil Fuels in Electricity Generation Sector

2.3.1. Motivation

In the previous section, I analyzed the crude oil price risk and clarified the decrease in the importance of diversifying import sources to reduce the risk. This result indicates that a portfolio selection changing only the shares of crude oil cannot decrease the energy price risk in the present. Next, I analyze a portfolio selection changing the shares of not only crude oil but also other types of fossil fuels to reveal whether the extended portfolio selection can decrease the energy price risk. In this section, I estimate not the optimal portfolio of whole the nation but that of the electricity generation sector by two reasons. First, the change in the energy portfolio of the electricity generation sector largely changes the portfolio in the nation because about 30 % of imported fossil fuels are consumed for the electricity generation [01]. Second, the energy portfolio of the electricity generation sector is relatively easier to be changed in comparison with that of other energy sectors. Some industries require a certain type of energy for their production; for example, the steel sector requires the coking coal and the transport sector requires the fuel oil. Their energy demands cannot be substituted by other types of energy in the short term because some technological developments are required. However, the energy portfolio of the electricity generation sector is relatively easier to be changed in comparison with those sectors because the sector already has technologies substituting material of electricity from crude oil to other types of fossil fuels. Then, I focus on the energy portfolio of the electricity generation sector in this section.

2.3.2. Modified Portfolio Analysis

All the studies reviewed in section 2.1 and the analyses in section 2.2 adopt the variances in the prices of import sources as an index of the energy price risk. However, the risk of fuel consumers does not increase in proportion to the variance because they suffer from only an increase in the prices of fossil fuels and rather obtain some profits from a decrease in them. This problem can be solved by adopting the upper semivariance (USV), defined as a squared average of only price deviations above the expected value, instead of the variance. If fuel prices are distributed symmetrically with respect to the expected value, the USV becomes a half of the variance, and the results of the analyses do not change irrespective of which value is used as a risk measure. However, the downward anomaly of the changes in the prices of fossil fuels has been observed by many studies [30] [31] [32]. Based on the observations, Yu [17] proposed to apply the mean-semivariance model utilizing the USVs as an index of the risk instead of the variance, and analyzed the US electricity market. This is the only study applying the mean-semivariance model to analyze the energy portfolio.

In addition to clarify the contribution of diversifying energy sources on the energy price risk of the electricity generation sector, I verify which is the better, the variance or USV, as an index of the energy price risk. Although the Sharp ratio, an index of the risk calculated from both the portfolio return and portfolio variance, is adopted in the previous section, I adopt only the portfolio valiance as an index of the risk. In the field of finance in which the portfolio analysis was firstly proposed, the purpose of decision makers is to maximize the profit from the portfolio of assets, and an index of the risk should be calculated from both the expected value and variance in the prices. However, in the field of energy policy, the purpose of decision makers is to mitigate the economic loss caused by an extreme increase in the price of fossil fuels. Then, the uncertainty in the price is more important than the average price.

As explained in the previous section, the mean-variance portfolio analysis estimates the energy price risk of certain energy portfolio from three factors: variances in the prices of each fossil fuel source, correlation coefficients among the prices, and the share of each fossil fuel source. The portfolio variances (PVar) in a fossil fuel mix containing N sources, represented by the equation (2-3), can be rewritten as

$$\sigma_p^2 = \sum_{i=1}^{N}\sum_{j=1}^{N} x_i x_j \rho_{ij} \sigma_i \sigma_j \tag{2-13}$$

where x_i is the share of source i, σ_i is the standard deviation in the price of fossil fuel source i, and ρ_{ij} is the correlation coefficient among the prices of fossil fuel sources i and j. On the other hand, the modified portfolio analysis adopting the USV instead of the variance can be obtained as follows. First, the USVs in each import source of fossil fuels can be represented as

$$\sigma_{i+}^2 = \frac{1}{T}\sum_{t=1}^{T} | r_{it} - \mu_i |_+^2 , \tag{2-14}$$

where $$| r_{it} - \mu_i |_+ = \begin{cases} r_{it} - \mu_i (r_{it} > \mu_i) \\ 0 (r_{it} \leq \mu_i) \end{cases}$$

by the definition. r_{it} is the price change rate of an import source i at time t, μ_i is the expected price change rate of an import source i. and T indicates the length of a dataset. Then, the portfolio upper semivariance (PUSV) can be obtained by substituting σ_i and σ_j in the equation (2-13) with the σ_{i+} and σ_{j+} as in the equation (2-14) as

$$\begin{aligned} \sigma_{p+}^2 &= \sum_{i=1}^{N}\sum_{j=1}^{N} x_i x_j \rho_{ij} \sigma_{i+} \sigma_{j+} \\ &= \sum_{i=1}^{N} x_i^2 \sigma_{i+}^2 + \sum_{i=1}^{N}\sum_{j=1}^{N} x_i x_j \sigma_{ij+} \end{aligned} \tag{2-15}$$

where $\sigma_{ij+} = \rho_{ij}\, \sigma_{i+}\, \sigma_{j+}$ ($i \neq j$). The first term in the equation (2-15) indicates the risk caused by each import source, and the second term indicates the risk caused by the interrelationship among the import sources. The first term takes a small value if import sources with small USVs are chosen. However, the second term does not become small unless the import sources less correlated are chosen.

The optimal energy portfolio minimizing the PUSV can be estimated by solving the quadratic programming problem

$$\min \quad {\sigma_{p+}}^2 \tag{2-16}$$

s.t. $$\sum_{i=1}^{N} x_i = 1 \qquad (2\text{-}17)$$

$$x_i \geq 0. \qquad (2\text{-}18)$$

2.3.3. Data and Analysis

Two sets of data are required to estimate the PVar and PUSV of an energy portfolio of the electricity generation sector: a share of each import source in the total import and a set of time series data in the prices of each import source. The shares are calculated for nine different import sources: coal from Asia, Oceania, and other countries (Others), oil from Asia, Middle East (ME), and Others, natural gas from Asia, ME, and Others [33]. The time series data in the import prices are estimated as follows. First, the monthly data of nominal CIF values and quantities of fossil fuel imported from each country are sourced from Japan Exports & Imports [29]; these are then categorized into the nine sources stated above. Second, the nominal values are converted into real values, and the quantities are converted into caloric values. Caloric values per unit quantity of coal, crude oil, heavy oil, and natural gas are 26.6 MJ/kg, 38.2 MJ/l, 41.7 MJ/l, and 54.5 MJ/kg, respectively [34]. In Japan, imported crude oil is consumed by the electricity generation sector in two ways: burned as crude oil directly or burned as heavy oil after refining. This study calculates a weighted average of the caloric value per unit quantity of crude oil and heavy oil and uses the weighted average to estimate a caloric value of crude oil imported for electricity generation. The weights of crude oil and heavy oil are calculated from energy balance tables [34]. Third, the time series dataset of the import prices is obtained by dividing the real values by caloric values.

Figure 2.3 presents the energy portfolio of the electricity generation sector in Japan during the period 1978–2007. The shares of crude oil have decreased, and those of coal and natural gas have increased over the analysis period. The shares of natural gas have increased mainly during the period from the late 1970s to the early 1980s, and those of coal have increased mainly in the 1990s. For natural gas, the import source has been diversified since 1990; the share of Middle East and other regions have increased. For coal, the import source has been diversified since the late 1990s; the share of Asia has increased.

Figure 2.4 presents the changes in prices of each import source. Regional

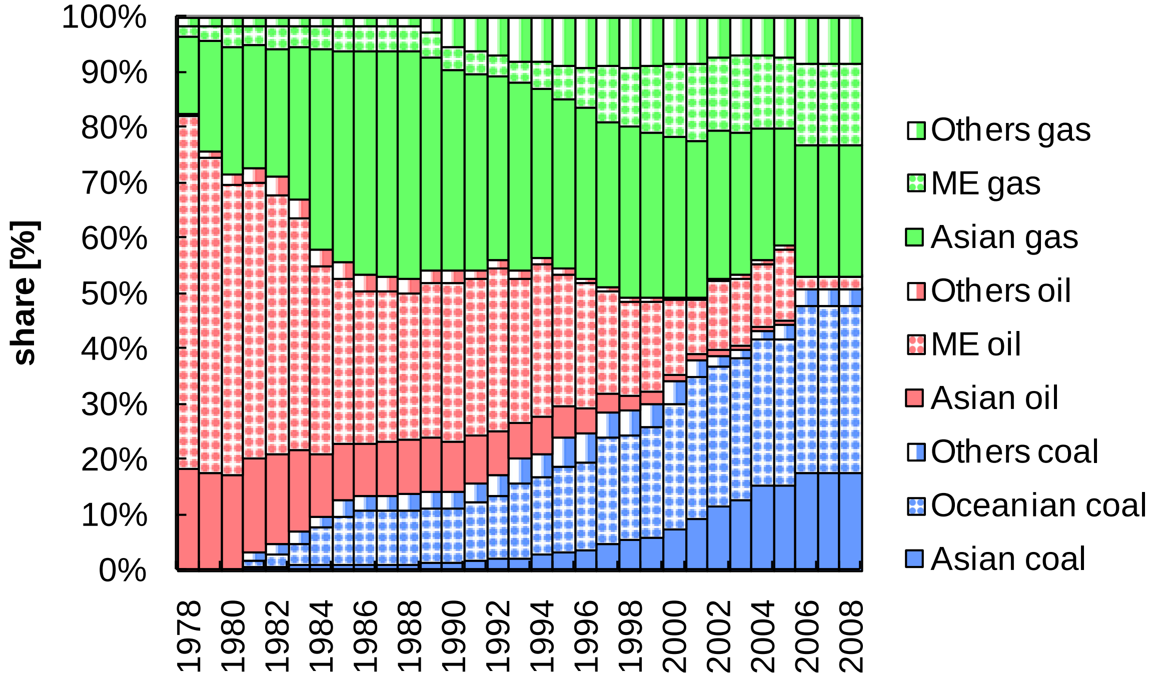


Figure 2.3 Fossil fuel mix chosen by the Japanese electricity generation sector.

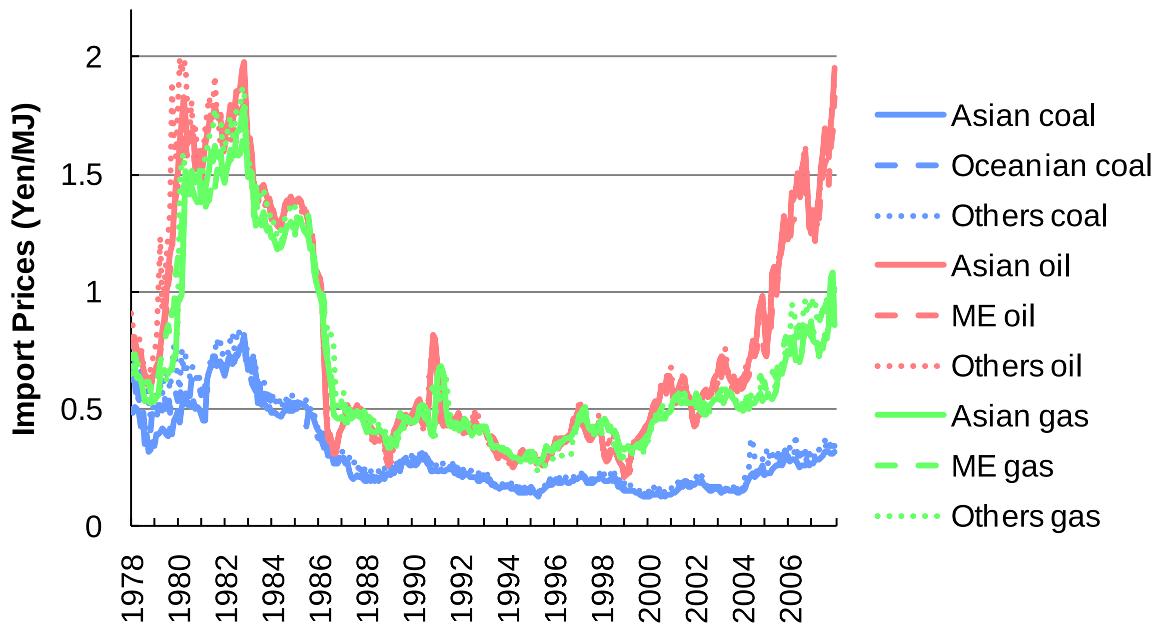


Figure 2.4 Changes in the import prices of fossil fuels.

differences in the prices are small over the analysis period, and differences between oil price and natural gas price are also small until 2003. There are three major price increases; the first is from 1979 to 1986; the second is from 1990 to 1991; the third is from 1998 to the present day.

In this study, the variances and USVs in the import prices and correlation coefficients among the prices are estimated by log-differenced price series of fossil fuel sources over a period of five years. For example, the values for January 1978 are estimated by a 60-period data from January 1973 to December 1977, and those for February 1978 are estimated by a 60-period data from February 1973 to January 1978. This moving-average like method was proposed by Regnier [35]. Table 2.4 presents the correlation coefficients among the price change rates of five fossil fuel sources with large share, and Table 2.5 presents the variances, the USVs, and the rates of USVs against variances. These lists present every three years' data for the month of December. If the prices of fossil fuels distribute symmetrically with respect to an expected value, USV becomes equal to a half of variance and consequently the rate of USV against variance becomes 50%. On the other hand, if downward anomalies of changes in fuel prices exist, the value becomes lower than 50%. After 1986, variances and USVs in Asian and ME oil price change rates are higher as compared to the other sources. Rates of USVs against variances are significantly lower than 50% in 1986 when the prices of oil and natural gas saw massive declines.

Figure 2.5 presents the PVar and PUSV in the energy portfolio of the electric utility sector in Japan estimated from equation are estimated from equations (2-14) and (2-15). Dashed and solid lines present the monthly PVar and PUSV, respectively. As shown in equation (2-15), the PUSV can be decomposed into two terms: the risk caused by the changes in the prices of individual fossil fuel sources and that caused by correlations among prices in the sources. The former is shaded deep gray and the latter is shaded light gray. Since Japanese electricity generation sector obtains benefit from the fall in fossil fuel prices, the energy price risk for the sector should not increase due to the downward anomalies in the price of fossil fuels. As shown in Figure 2.5, PVar has an extreme peak from 1986 to 1989 that was caused by the downward anomalies in the price of oil and natural gas. On the other hand, PUSV do not have an extreme peak in the period. Thus, it is empirically confirmed that PUSV is a better measure of the energy price risk in the electricity generation sector than PVar.

The electricity generation sector reduced the energy risk caused by the prices of individual import sources, but not the risk caused by correlations among the prices of import sources. The first term in the equation (2-15) decreases in 1994, and then remained at a relatively low level until 2007 despite of an increase in the prices of

Table 2.4: Correlation coefficients among log-differenced prices of each import source (for the month of December).

	coal of Asia				coal of Oceania			oil of ME		gas of Asia
	coal of Oceania	oil of ME	gas of Asia	gas of ME	oil of ME	gas of Asia	gas of ME	gas of Asia	gas of ME	gas of ME
1980	–0.069	0.023	0.31	0.49	0.2	0.062	0.12	0.14	0.14	0.91
1983	0.19	0.46	0.28	0.35	0.13	0.57	0.52	0.2	0.32	0.91
1986	0.22	0.46	0.36	0.42	0.15	0.31	0.37	0.3	0.35	0.95
1989	0.25	0.42	0.28	0.3	0.47	0.36	0.44	0.34	0.36	0.95
1992	0.27	0.29	–0.051	–0.12	0.35	–0.016	0.03	–0.005	–0.038	0.89
1995	0.79	0.38	0.32	0.3	0.31	0.37	0.38	–0.047	0.064	0.76
1998	0.76	0.42	0.57	0.48	0.49	0.49	0.49	0.39	0.35	0.92
2001	0.59	0.25	0.2	0.12	0.34	0.15	0.072	–0.047	–0.056	0.92
2004	0.67	0.55	0.18	0.18	0.39	0.16	0.17	–0.12	–0.045	0.83
2007	0.5	0.42	0.13	0.14	0.31	0.13	0.28	–0.13	–0.04	0.86

Table 2.5 Variance and USV in the log-differenced prices of each import source (for the month of December).

		Coal			Oil			Gas		
		Asia	Oceania	Others	Asia	ME	Others	Asia	ME	Others
1980	Var	0.0015	0.0023	0.0024	0.00056	0.00055	0.0024	0.0011	0.00056	n.a.[a]
	USV	0.0006	0.0013	0.0013	0.00029	0.00027	0.0013	0.0008	0.00032	n.a. [a]
	Rate	39%	56%	54%	51%	49%	55%	74%	57%	n.a. [a]
1983	Var	0.0014	0.00055	0.00065	0.0003	0.00025	0.00031	0.00033	0.00034	0.00042
	USV	0.00078	0.00028	0.00028	0.0001	0.00009	0.00013	0.00011	0.00014	0.00014
	Rate	57%	52%	42%	34%	38%	42%	35%	41%	32%
1986	Var	0.00026	0.0004	0.00073	0.0018	0.0018	0.0021	0.00045	0.00044	0.00062
	USV	0.00009	0.00022	0.00035	0.00045	0.00051	0.00047	0.00012	0.00014	0.00013
	Rate	36%	55%	48%	25%	28%	22%	27%	31%	21%
1989	Var	0.00088	0.00028	0.00073	0.00067	0.00071	0.00087	0.00042	0.00031	0.00058
	USV	0.00042	0.00014	0.00035	0.00035	0.00035	0.00049	0.00025	0.00015	0.00028
	Rate	48%	50%	48%	52%	50%	55%	59%	49%	48%
1992	Var	0.00034	0.00014	0.00054	0.0014	0.0018	0.0027	0.0013	0.00027	0.0018
	USV	0.00019	0.00009	0.00021	0.00073	0.00091	0.0016	0.00078	0.00018	0.0012
	Rate	54%	62%	38%	53%	52%	60%	62%	66%	68%
1995	Var	0.00036	0.00031	0.00088	0.00032	0.00029	0.00078	0.00027	0.00019	0.00022
	USV	0.00022	0.00016	0.00054	0.00017	0.00016	0.00035	0.00015	0.00011	0.00011
	Rate	62%	54%	61%	54%	56%	45%	55%	55%	51%
1998	Var	0.00023	0.00020	0.00067	0.00077	0.00074	0.0022	0.00038	0.00031	0.00068
	USV	0.00008	0.00006	0.00028	0.00035	0.00029	0.00093	0.00014	0.00015	0.0004
	Rate	36%	30%	42%	45%	39%	43%	37%	47%	59%
2001	Var	0.00028	0.00026	0.0014	0.0011	0.0011	0.003	0.00016	0.0002	0.00018
	USV	0.00014	0.00013	0.00063	0.00039	0.00041	0.0016	0.00009	0.0001	0.00009
	Rate	50%	52%	47%	37%	38%	53%	57%	47%	50%
2004	Var	0.00037	0.0011	0.002	0.00055	0.00061	0.00047	0.00022	0.00016	0.00018
	USV	0.00022	0.00064	0.0014	0.00025	0.00026	0.0002	0.00008	0.00008	0.00009
	Rate	60%	59%	67%	46%	42%	42%	39%	47%	47%
2007	Var	0.00024	0.00022	0.0023	0.001	0.00056	0.00064	0.00094	0.00031	0.00063
	USV	0.00008	0.00011	0.0013	0.00043	0.00024	0.00028	0.00038	0.00014	0.00034
	Rate	35%	51%	56%	41%	44%	44%	40%	46%	54%

[a]Those values cannot be estimated because of the lack of data.

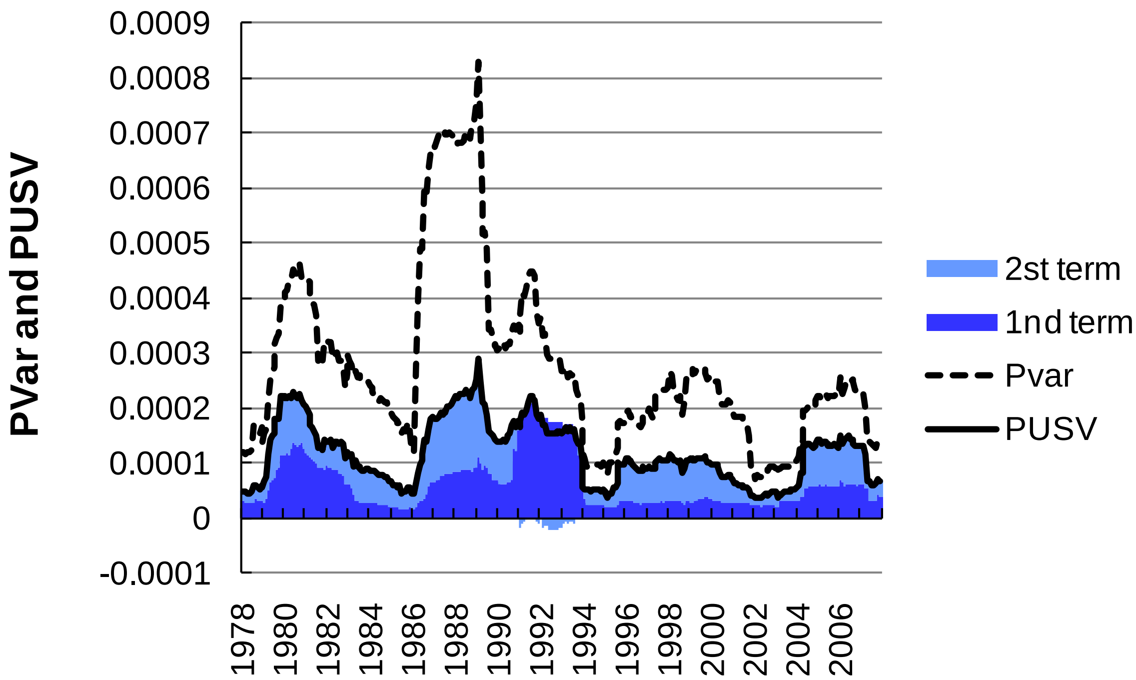


Figure 2.5 Portfolio variance and semivariance in the energy portfolio of the electric utility sector.

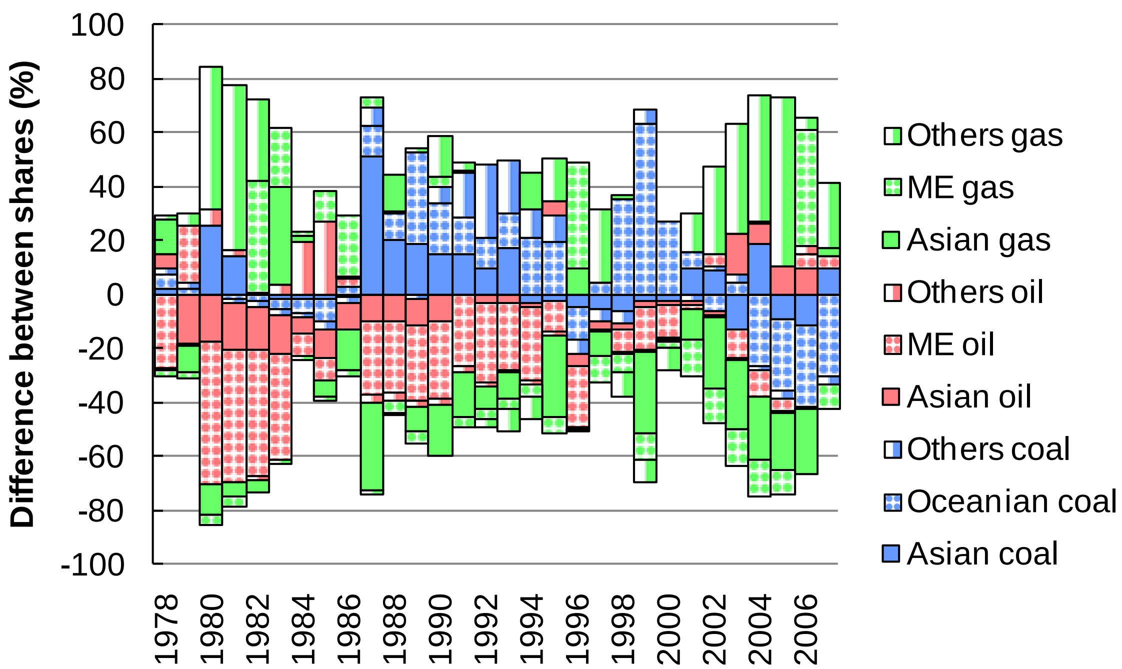


Figure 2.6 Differences in the share of import sources between the optimal and actual energy portfolio of the electricity generation sector.

fossil fuels after 1998. However, the second term was at its lowest level in 1994; it showed an increase both in the late 1990s and the 2000s. It is conceivable that the energy price risk of individual import sources are easy to estimate since it has a consistent trend; USVs in the prices of Asian and ME oil are higher than those in the prices of Asian and Oceanian coal during almost the entire period. Thus, the electricity generation sector can decrease the first term of equation (2-15) by substituting oil with coal and natural gas, as is shown in Figure 2.3. On the other hand, estimating correlations among the prices of fossil fuels seems to be difficult as correlation coefficients have no simple trends, as shown in Table 2.4.

Next, I estimate the optimal energy portfolio minimizing the PUSV by solving the quadratic programming problem presented by equation (2-16), (2-17), and (2-18) for every month in the analysis period. Figure 2.6 presents the differences in the share of each import source between the optimal and actual energy portfolio. To minimize the energy price risk, the import sources with positive differences need to be increased, and those with negative difference need to be decreased.

The analysis period can be divided into three sub-periods by differences in the breakdown of rates: 1978–1986, 1987–2001, and 2002–2007. In the first sub-period, the energy price risk can be decreased mainly by substituting oil with natural gas. In the second sub-period, the risk can be decreased mainly by substituting oil and natural gas with coal. In the third sub-period, the differences are more complex than in the previous sub-periods. Others natural gas needs to be increased, while Oceanian coal, Asian natural gas, and ME natural gas need to be decreased.

Figure 2.7 presents the PUSV for the optimal and actual portfolio in each month. All the three sub-periods defined above include a large deviation between a PUSV in the optimal and actual portfolio indicating the margin of changing the portfolio to decrease the risk. Different from the energy price risk of importing crude oil for Japan, the energy price risk of importing fossil fuels for the electricity generation sector can be decreased by changing the energy portfolio even in the 2000s.

As presented in Figure 2.3, the electricity generation sector in Japan has changed its energy portfolio toward the optimal portfolio in the first and second sub-periods. From 1980 to 1986, the share of oil has decreased by 32%, while that of natural gas has increased by 19%. From 1986 to 2001, the share of oil has decreased by 29%, while that of coal has increased by 25%; the share of natural gas has remained the same. Actually, difference between a PUSV in the optimal and actual portfolio has decreased during the first and second sub-periods. From 2001 to 2007, however, the share of Others natural gas did not increase, whereas the share of Oceanian coal and ME natural gas did. Two reasons are considered to explain the

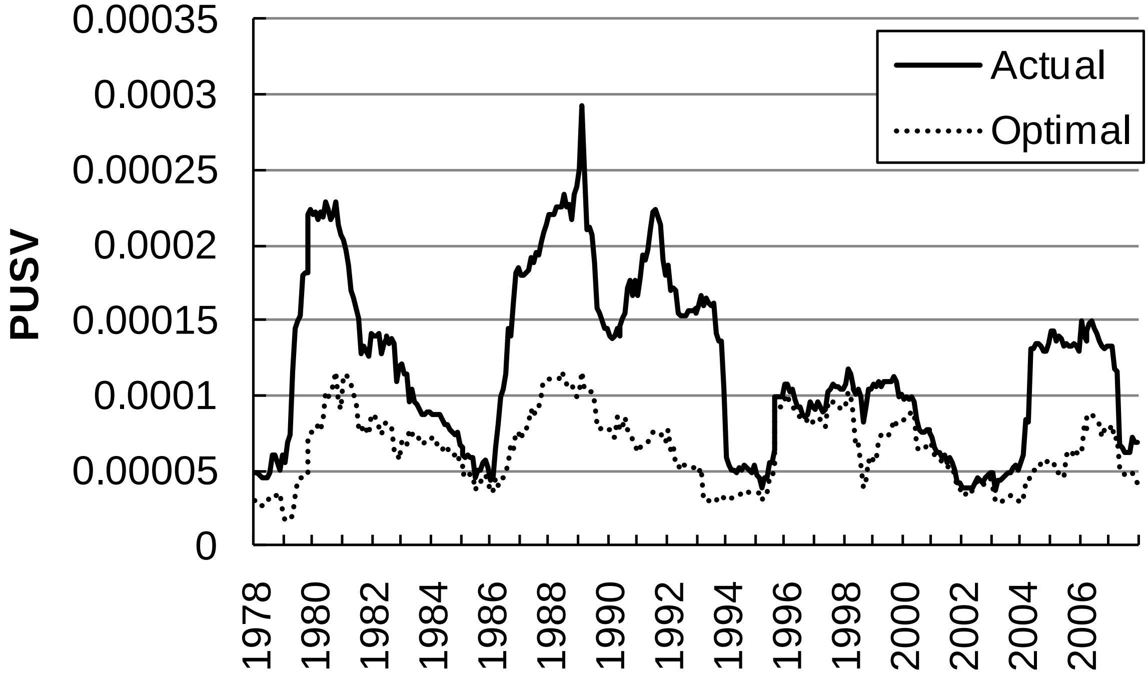


Figure 2.7 PUSV of the optimal and actual portfolio in each month.

differences between the optimal and actual energy portfolio since 2001. First, the share of natural gas is difficult to decrease immediately as the transition needs large amounts of initial investments to construct the entire gas supply system. Second, the change in a fossil fuel mix that lowers the risk is more complex in the third sub-period than in previous sub-periods. Substitution between the various fuels and between the regions from which these fuels are sourced is required.

2.4. Discussions

There are three major findings from the preliminary analyses in this chapter. First, an index of the energy price risk needs to focus on only the price deviation above the expected value. The portfolio upper semivariance is the better measure of the risk than the portfolio variance because the semivariance can exclude the influence of the price deviation below the expected value. Second, not only crude oil but also other types of fossil fuels need to be included in the portfolio analysis. Although the portfolio diversification among the import sources of crude oil cannot decrease the energy price risk in the 2000s, the portfolio diversification among the import sources of three types of fossil fuels, i.e. coal, crude oil, and natural gas, can decrease the energy price risk further. Third, Japanese electricity generation sector decreased the risk caused by an individual import source of fossil fuels, but failed to decrease the risk caused by correlations among prices of the import sources. The former is reduced by substituting crude oil with coal and natural gas during the period 1978–1985 and 1986–2001, respectively. Since electricity is consumed by almost all domestic industries, this reduction of the risk has contributed to enhance the energy security of those sectors. The latter is more difficult to mitigate because the correlations among the import sources have few trends. One hint to tackle the problem is that correlation among the prices of the same type of fossil fuels are more strongly correlated than the prices of different types of fossil fuels. Then, the portfolio diversification among the different types of fossil fuels needs to be given a preference than the diversification among the different regions.

Chapter 3

I–O Portfolio Analysis

3.1 Literature Review

Although the energy price risk of Japanese energy conversion sector is quantified by applying the standard portfolio analysis, the method has two disadvantages. First, the standard portfolio analysis cannot endogenize the final energy selection by non-energy sectors. Especially, the material sectors consume a large amount of energy for their production, and their energy cost is indirectly affected by the import prices of fossil fuels. Actually, the Japanese chemical, steel, and metal products sectors were increased their producer prices by 90%, 70%, and 80%, respectively, during the terms of the two oil crises [36]. To focus on the risk of non-energy sectors, their energy selections need to be included in the analytical framework. Second, the standard portfolio analysis cannot endogenize a national industrial structure. The energy price risk can be propagated through inputs of not only energy products but also non-energy products. For example, the steel sector consumes cements when building factories. At that time, the steel sector indirectly consumes energy because the cement sector consumes energy for its production. Similarly, the electricity generation sector indirectly consumes energy by building generation plants made of steel and cement.

Both the disadvantages have a common cause: ignored interrelationship among domestic sectors. There are two types of energy price risk: direct and indirect energy price risk. The former arises from consuming primary energy, and the latter arises from consuming final energy and non-energy products. In order to quantify both the risks, overall input–output structure in a nation needs to be endogenized into analytical framework because the amount of indirect influence is determined by the structure of various production chains.

The I–O analysis, proposed by Leontief [37] [38], has been applied to estimate both the direct and indirect energy intensity, i.e. the direct and indirect energy consumption per unit production, in the industrial sectors. The I–O analysis can include all product chains in the national industrial structure because the analysis utilizes an I–O table that records all annual money flows among domestic sectors. Bullard and Herendeen [39] proposed the energy I–O analysis, and estimated the energy intensity and energy cost in the automobile sector in the United States. The

I–O analysis is also applied to estimate the direct and indirect emission intensity of environmental pollutant and CO_2 [40] [41] [42]. However, these energy and environmental I–O analysis are not suitable for our purpose because they assume constant prices of all goods and services.

The Leontief price model [38] [40], which is based on the I–O model, can quantify both the direct and indirect influences of an increase in the price of imported energy. The Leontief price model assumes constant flows of all goods and services, and examines how much percentage the prices of every goods and services increase when the prices of production factors, including fossil fuels, increase. This model has been applied to quantify the energy intensity in domestic sectors and to clarify the relationship between the intensity and industrial structure of various countries such as Korea [43] [44], Turkey [45], Vietnam [46], and Japan [47] [48][3]. However, the conventional Leontief price model cannot endogenize uncertainty in the price of fossil fuels.

Lian et al. [54] and Santos [55] proposed probabilistic interdependency analysis (PIA) enabling 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 analyze a risk of large-scale infrastructure and economic systems, and has been applied to the analysis of cybersecurity [56] and biofuel subsidy [57]. The outputs of this model are probabilistic variables because the inputs of the model, demand perturbation caused by risk events, are also probabilistic variables. The CVaR is applied as the risk index. Although this method can provide key idea to combine the portfolio analysis and Leontief price model, there is no study applying PIA to quantify the energy price risk.

In addition to quantifying the energy price risk, the main causes of the risk and the time series changes in the risk need to be clarified. The Structural Path Analysis (SPA), which decomposes an output of the I–O model into a contribution of each path, has been applied for the purpose. Each path refers to each product chain starting from an upper factor of a production chain and ending with the final product [58]. For each path, a path value is defined as the continued product of all the input coefficients, defined as the cost of one sector as a payment per unit of production to another sector, included in the path. In the Leontief price model, the path value indicates the contribution of a path to the producer price of a product produced by the path. Treloar [59] firstly introduced the SPA for the energy I–O analysis focusing on the residential

[3] Recently, the Leontief price model has also been applied to the analysis of the effects of energy and environmental policies. Labandeira and Labeaga [49] and Choi et al. [50] analyzed the effects of carbon taxes, Llop and Pié [51] and Liu et al. [52] analyzed the effects of a tax on energy consumption, and Llop [53] analyzed the effects of a tax on water consumption.

building sector in Australia, and clarifies that large part of energy consumption by the sector is consumed by few numbers of path, such as a path producing clay product, cement, and steel. Lenzen [60] analyzed environmental load in Australia, and clarified that the husbandry products for export, such as beef cattle, beef meet, and wool products, makes the largest environmental load in the country. After that, the SPA is widely applied to the life cycle assessment (LCA) of energy consumption [61] [62] [63] and environmental load [64] [65] because the SPA can easily estimate the direct and indirect energy consumption and environmental load.

However, the SPA is not suitable for the purpose of this dissertation because this method is too microscopic. In the case of an industrial structure including dozens of sectors and hundreds of inputs, and is an usual case when analyzing an actual industrial structure, an output of the model is decomposed into constituent parts of thousands of paths. As a result, we have a trouble to choose a path that is important for the purpose of the analysis. Then, we need more aggregated type of decomposition analysis.

This dissertation proposes a new analytical framework combining the portfolio method and Leontief price model, based on the concept of the PIA, and estimates the risk of an increase in the producer prices of domestic sectors. This analytical framework can endogenize four factors presented in Chapter 1: difference in the uncertainty among the prices of each type of fossil fuels, primary energy selection by energy conversion sectors, final energy selection by non-energy sectors, and indirect energy consumption relying on national industrial structure. Further, this dissertation proposes to decompose an index of the energy price risk, CVaR, based on the two points of view: the type of energy causing the energy price risk for a sector, and which is the main cause of the risk, direct and indirect input of energy, instead of the SPA. Such an aggregated type of decomposition can contribute to clarify the cause of the energy price risk.

3.2. Methodology

The I–O portfolio analysis consists of three steps: Monte Carlo simulation, calculation of the risk index, and decomposition of the risk index. The Monte Carlo simulation consists of three steps. First, yearly change in the prices of fossil fuels and CO_2 are estimated using the GBM model. Second, the producer prices of domestic sectors are estimated by applying the Leontief price model. Third, increases in the total expenditure of the final consumption sectors, such as the household and government sectors, are estimated. As a result of the Monte Carlo simulation, probabilistic density functions of the change in the producer prices and total expenditures of each sector are obtained. Next, the CVaRs in those changes can be estimated from the probabilistic density functions. Finally, the CVaRs are decomposed into direct and indirect input factors of each types of energy.

3.2.1. Modeling Uncertainty in Prices of Fossil Fuels

The characteristics of the change in the prices of energy have been concerned by many researchers especially after the establishment of energy markets such as West Texas Intermediate (WTI) oil market in New York Mercantile Exchange (NYMEX) and Brent market in International Petroleum Exchange (IPE).

The autoregressive model has been most commonly applied to quantify the characteristics of those markets. For example, Batlle and Barquı´n [66] proposed the method to generate oil and gas price scenarios utilizing stochastic volatilities detected in actual commodity markets. Worthington et al. [67] clarified the spillover effects among the regional electricity markets in Australia. Mohammadi and Su [68] estimated the time series properties of crude oil prices in 11 countries. Those studies apply the multivariate GARCH [69] model, a kind of autoregressive model with the short term memory in the market prices, and its expansions.

Another important model for the energy market analysis is the MF-DFA. The autoregressive model, such as GARCH model, cannot remove the non-steady trends in energy markets caused by incidents outside the markets, such as the wars and resource nationalism. On the other hand, the MF-DFA can remove those trends in the markets and can focus on the key characteristics in the markets, i.e. the fat tail and long term correlation. For example, Norouzzadeh et al. [70] applied the MF-DFA to the Spanish electricity market and concluded that the multiflactarity due to the long-term correlations has less contribution than the fat tail of the probability density function to the characteristic of the market price. Alvarez-Ramirez et al. [71] applied the MF-DFA to the WTI oil market price, and found the auto-correlations for the time horizon smaller than a month. Engelen et al [72] applied the MF-DFA to the spot price of liquid petroleum gas (LPG) on the Persian Gulf to Japan route, and find the fat tail character in the market.

The problem of the autoregressive and MF-DFA is that we need time series data of the market prices with relatively short interval, such as weekly, daily, or hourly, because those methods require a large amount of data for the analysis. Then, although those models can provide detailed information about the markets, they can only be applied to the markets whose prices are recorded at shorter interval than a week and disclosed to researchers. On the other hand, the studies focusing on not only the energy markets but also whole the energy system need to estimate the price changes in markets with fewer information, such as the coal and natural gas markets, and require only the rough description of markets. Then, such a type of studies apply much simpler models than the autoregressive and MF-DFA model, such as the GBM and MR models, to describe the characteristics of the energy markets [24] [25] [73][4], or set the market price constant [74].

This dissertation adopts the GBM to describe the uncertainty in the prices of fossil fuels and CO_2. The constant price method cannot be adopted because the uncertainty in the prices of fossil fuels needs to be endogenized into the analytical framework. However, it is difficult to obtain time series data of the market prices with relatively short interval; we can obtain only monthly data of the import prices of fossil fuel for Japan. Then, we adopt the GBM model to describe the import prices of them. Although the MR model may be more accurate to represent the characteristics of those markets, some earlier studies show that the hypothesis that energy price follows the GBM cannot be rejected in a 30-year scale [75] [76]. Moreover, the GBM model can be operated easier than the MR model and can be estimated from smaller size of data because it has fewer parameters than the MR model. And for the price of CO_2, there is no reliable historical series from which information can be extracted to estimate a suitable stochastic process because the history of the carbon trading market is rather short [77]. Therefore, we assume that the price of CO_2 can also be described by the GBM model following earlier studies such as [24] [73] [77] [78].

The prices of fossil fuel i and CO_2 in time τ can be represented as

$$\ln q_i(\tau+1) - \ln q_i(\tau) = \mu_i + \varepsilon_i(\tau) \Leftrightarrow q_i(\tau+1) = q_i(\tau)\exp\{\mu_i + \varepsilon_i(\tau)\}, \tag{3-1}$$

$$\ln q_c(\tau+1) - \ln q_c(\tau) = \mu_c + \varepsilon_c(\tau) \Leftrightarrow q_c(\tau+1) = q_c(\tau)\exp\{\mu_c + \varepsilon_c(\tau)\}, \tag{3-2}$$

where ε_i and ε_c are stochastic processes following $N(0,\sigma_i^2)$ and $N(0,\sigma_c^2)$, μ_i and μ_c are drift parameters, and σ_i and σ_c are volatility parameters in the price of fossil fuel i and CO_2, respectively. One time step corresponds to one year. By denoting a base year as $\tau = 0$, an yearly increase in the prices of fossil fuels and CO_2 in $\tau = 1$, ΔQ^E and ΔQ^c,

4 Some earlier studies show that the hypothesis that energy price follows the GBM cannot be rejected in a 30-year scale [75] [76], and the GBM model is an easy method for estimating input parameters.

can be represented as

$$\Delta Q^{E} = q_i(1)/q_i(0)\exp\{\mu_i + \varepsilon_i(0)\}\,. \tag{3-3}$$

$$\Delta Q^{C} = q_c(1)/q_c(0)\exp\{\mu_c + \varepsilon_c(0)\}\,. \tag{3-4}$$

We assume that all costs for CO_2 emission are added to the fuel costs for the electricity generation sector. Under this assumption, the price of fossil fuel *i* including CO_2 cost can be represented as

$$q_i'(\tau) = q_i(\tau) + \gamma_i q_c(\tau)$$

$$\Leftrightarrow q_i'(\tau+1) = q_i(\tau)\exp\{\mu_i + \varepsilon_i(\tau)\} + \gamma_i q_c(\tau)\exp\{\mu_c + \varepsilon_c(\tau)\}\,, \tag{3-5}$$

where γ_i is CO_2 emission per unit consumption of fossil fuel *I*, and q_i with prime (′) indicate the price of fossil fuels including CO_2 cost. As a result, the prices of fossil fuels in $\tau = 1$, $q_i'(1)$, and an increase in the prices of fossil fuels over a year, Δp_i^m, can be represented as

$$q_i'(1) = q_i(0)\exp\{\mu_i + \varepsilon_i(0)\} + \gamma_i q_c(0)\exp\{\mu_c + \varepsilon_c(0)\} \tag{3-6}$$

$$\Delta p_i^m = q_i'(1)/q_i'(0)\,. \tag{3-7}$$

3.2.2. Leontief Price Model

The Leontief price model estimates a change in the rate of producer prices in domestic sectors caused by an exogenous change in the price of production factors. Note that the price in this model is a shadow price determined from only costs for materials and production factors. The producer prices of each sector in equilibrium condition can be represented as

$$R = A^t R + V\,, \tag{3-8}$$

where *R* indicates the producer price in each sector, *A* indicates the input coefficients, i.e., the cost of one sector as a payment per unit of production to another sector, and *V* indicates a payment per unit of production to production factors.

In this study, I need to focus on indirect influences of an increase in the prices of imported fossil fuels on the prices of domestic products. For the purpose, the equation (3-8) needs to be modified to distinguish domestic and imported products. By using the import coefficient vector, *M*, whose elements indicate the ratio of imported supply to the total supply for each sector, the equation (3-1) can be modified as

$$P = B^t P + G^t Q + V \ , \qquad (3\text{-}9)$$

where *P* and *Q* indicate the domestic and import prices in each sector, respectively, $G = \hat{M}A$ indicates the input coefficients from the foreign to domestic sectors, $B = (I - \hat{M})A$ indicates the input coefficients among the domestic sectors, and *I* indicates an identity matrix whose dimension is equal to that of *A*. The superscript *t* indicates transposition of a vector or a matrix, and the superscript ^ indicates diagonalization of a vector.

All elements of *P* and *Q* are normalized to one in the equilibrium condition. When *Q* increases by Δ*Q* from the equilibrium condition and *V* does not change, an increase in *P*, Δ*P*, can be estimated as

$$\Delta P = (I - B^t)^{-1} G^t \Delta Q \ . \qquad (3\text{-}10)$$

In this dissertation, consumption of energy and non-energy products needs to be distinguished to clarify the share of direct and indirect energy price risk in each sector. Then, the price vectors and the input coefficient matrices must be decomposed as

$$P = \begin{bmatrix} P^E \\ P^N \end{bmatrix} \quad Q = \begin{bmatrix} Q^E \\ Q^N \end{bmatrix} \quad B = \begin{bmatrix} B^{EE} & B^{EN} \\ B^{NE} & B^{NN} \end{bmatrix} \quad G = \begin{bmatrix} G^{EE} & G^{EN} \\ G^{NE} & G^{NN} \end{bmatrix}. \qquad (3\text{-}11)$$

The superscripts *E* and *N* denote the sets of energy and non-energy sectors, respectively. P^X and Q^X indicate the domestic and import prices in sectors in set *X*, and B^{XY} and G^{XY} indicate the cost of the domestic sectors in set *Y* as a payment per unit production to the domestic and import sectors in set *X*, respectively. For example, Q^E indicates the import prices of energy sectors, G^{EN} indicates a set of input coefficients from the foreign energy sectors to domestic non-energy sectors, and B^{NN} indicates a set of input coefficients among the domestic non-energy sectors. Substituting the equation (3-11) for (3-9), an increase in the domestic prices of energy and non-energy sectors, ΔP^E and ΔP^N, can be represented as

$$\Delta P^E = \{I^E - (B^{EE})^t\}^{-1}\{(B^{NE})^t \Delta P^N + (G^{EE})^t \Delta Q^E\} \tag{3-12}$$

$$\Delta P^N = \{I^N - (B^{NN})^t\}^{-1}\{(B^{EN})^t \Delta P^E + (G^{EN})^t \Delta Q^E\}, \tag{3-13}$$

where I^X indicates an identity matrix whose dimension is equal to that of B^{XX}. In this study, we assume that the import price of only the energy sectors increases; the import price of non-energy sectors does not change from the equilibrium condition to focus on an influence of the energy price increase.

3.2.3. Risk Index

An input of the equation (3-12) and (3-13), ΔQ^E, is given as a probabilistic variable to estimate the price risk in each energy market and price correlations among the energy markets. Then, outputs of those equations, ΔP^E and ΔP^N, are also given as probabilistic variables. In the I–O portfolio analysis, an index of the energy price risk is estimated from the probabilistic distribution of the outputs same as the PIA. The problem is that which statistic should be adopted as an index of the energy price risk. In the previous chapter, I adopted the PUSV as an index of the energy price risk and clarified that the PUSV is the better measure of the risk than the PVar. However, those indices have two common problems. First, the PVar and PUSV cannot focus on the extreme changes in the prices of fossil fuels, i.e. shape of tail distribution in the probabilistic density of ΔP^E and ΔP^N, because they are defined as the average of price deviations. Second, they are not suitable for decomposition analysis because they do not have additivity.

The value-at-risk (VaR) is defined as the maximum energy cost with a given level of confidence under a certain energy mix [16] [19]. An advantage of the VaR is that it can focus on extreme changes in the prices of fossil fuels. However, VaR possesses two disadvantages: ignoring the shape of tail distribution, and undesirable mathematical characteristics such as a lack of subadditivity, convexity, and positive homogeneity [79] [80] [81]. Fortin et al. [24] proposed to use the CVaR defined as the conditional expected cost beyond a given level of confidence under a certain energy mix because it can convert the shape of a tail distribution into the risk index, and has additivity, convexity, and positive homogeneity. We agree with this proposal and use the CVaR as an index of the energy price risk.

From the definition, the CVaR in the output of equation (3-12) and (3-13) over the confidence level β are estimated as

$$CVaR^{X} = (1-\beta)^{-1}\int_{\Delta P^{X} \geq \alpha_{\beta}^{X}} \Delta P^{X} \pi(\Delta Q^{E}) d\Delta Q^{E} \tag{3-14}$$

where X denotes a set of the domestic energy or non-energy sectors, $\pi(\Delta Q^E)$ denotes a probabilistic density function of ΔQ^E, and $\alpha_\beta{}^X$ denotes threshold values defined as the maximum value of ΔP^X under the confidence level β.

3.2.4. Decomposing Risk Index

As I mentioned in section 3.1 the more aggregated type of decomposition analysis than the SPA is required for the purpose of this dissertation. Then, this dissertation proposes two-step decomposition of the CVaR. In the first step, the CVaR is decomposed into constituent parts of each type of energy. The constituent parts are denoted as the input factors of each type of energy hereafter. Those input factors indicate which type of energy is the main factor of the energy price risk in a certain domestic sector. In the second step, those input factors are further decomposed into direct and indirect influence. The result of the second step indicates the main factor of the energy price risk: a direct consumption of energy or an indirect consumption of energy passing through other sectors.

Figure 3.1 explains the proposed decomposition method by using figure of a simplified I–O structure around the automobile sector. There are seven inputs: the crude oil to oil product sector, the crude oil to electricity generation sector, the coal to electricity generation sector, the oil product to chemical product sector, the oil product to automobile sector, the electricity generation to the automobile sector, and the chemical product to automobile sector. The producer price of automobile sector is increased by an increase in the prices of fossil fuels (there are only two types of fossil fuels in this simplified I–O structure) passing through the seven inputs included in the I–O structure. In this study, the total increase in the producer price of the automobile sector is decomposed into constituent parts by two steps as explained above. First, the total increase is decomposed into two input factors: input factors of the oil product represented by blue arrows, and that of electricity generation sector represented by a red arrow, respectively. Second, those input factors are decomposed into direct and indirect input factors; the former and the latter is represented by solid and dot lines, respectively.

The producer prices of the domestic energy sectors, ΔP^E, can be

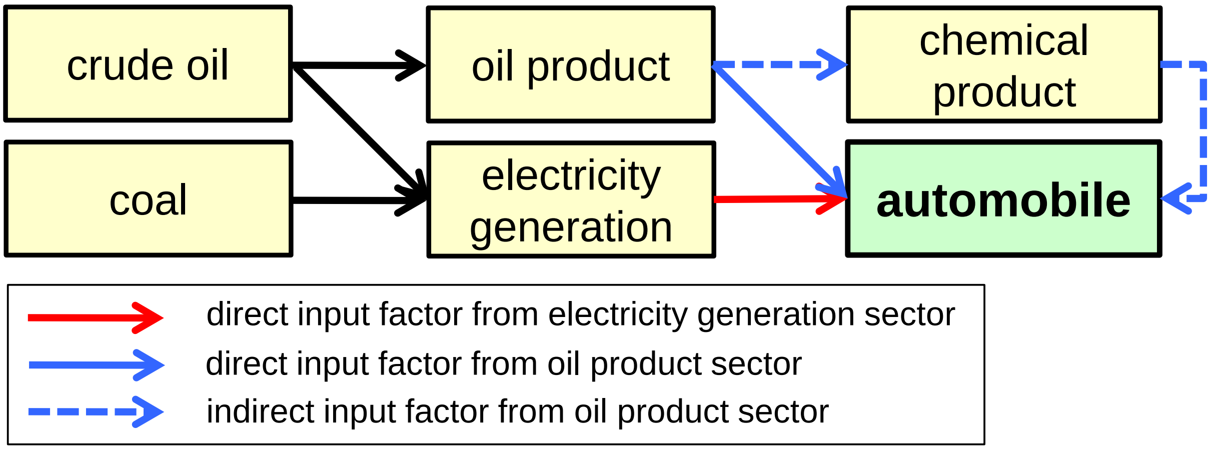


Figure 3.1 Conceptual figure explaining the method decomposing the risk index proposed by this dissertation.

decomposed into input factors of imported energy products and domestic non-energy products. ΔQ^E can be decomposed into increases in the import prices of each type of energy product as

$$\Delta Q^E = \sum \Delta Q_i^E \ , \qquad (3\text{-}15)$$

where the ith element of ΔQ_i^E is equal to that of ΔQ^E, and other elements of ΔQ_i^E are zero. By substituting the equation (3-15) for (3-12), we obtain

$$\Delta P^E = \sum \Delta P_i^{Qe} + \Delta P^{Pn} \ , \qquad (3\text{-}16)$$

where $\Delta P_i^{Qe} = \{I^E - (B^{EE})^t\}^{-1}(G^{EE})^t \Delta Q_i^E$

and $\Delta P^{Pn} = \{I^E - (B^{EE})^t\}^{-1}(B^{NE})^t \Delta P^N$.

The first term in the equation (3-16) indicates the input factor of imported energy, and the second term indicates input factor of domestic non-energy products. These terms can be further decomposed into direct and indirect influences. For example, ΔP_i^{Qe} can be decomposed as

$$\begin{aligned}\Delta P_i^{Qe} &= [I^E + (B^{EE})^t + \{(B^{EE})^t\}^2 + \{(B^{EE})^t\}^3 + \cdots](G^{EE})^t \Delta Q_i^E \\ &= (G^{EE})^t \Delta Q_i^E + \sum_{i=1}^{\infty} \{(B^{EE})^t\}^i (G^{EE})^t \Delta Q_i^E \ , \end{aligned} \qquad (3\text{-}17)$$

where the first and second terms indicate the direct and indirect input factors of the energy product i, respectively. Other input factors in the equation (3-16) can be similarly decomposed into direct and indirect factors.

For the non-energy sectors, we decompose ΔP^N into the input factors of imported and domestic energy. ΔQ^E and ΔP^E can be decomposed into increases in the imported and domestic prices of each type of energy as

$$\Delta Q^E = \sum \Delta Q_i^E \ , \quad \Delta P^E = \sum \Delta P_i^E \ , \qquad (3\text{-}18)$$

where the ith elements of ΔQ_i^E and ΔP_i^E are equal to those of ΔQ^E and ΔP^E, respectively, and other elements are zero. By substituting the equation (3-18) for (3-13), we obtain

$$\Delta P^N = \sum \Delta P_i^{Qn} , \quad (3\text{-}19)$$

where $\Delta P_i^{Qn} = \{I^N - (B^{NN})^t\}^{-1}(G^{EN})^t(\Delta Q_i^E + \Delta P_i^E)$.

While ΔP_i^{Qn} in the equation (3-19) can be decomposed into the input factors of imported and domestic energy products, this study reports only ΔP_i^{Qn}, i.e., the input factor that includes both the foreign and domestic input factors, to focus on the types of goods and services consumed by the domestic sectors. ΔP_i^{Qn} can also be decomposed into the direct and indirect input factors in the same manner as that in the equation (3-17).

The CVaR in the prices of the domestic energy and non-energy sectors can be decomposed into the direct and indirect input factors of each types of energy by substituting the equation (3-19) for (3-14). The result of this decomposition can clarify the cause of the change in the risk in the past and the main causes of the risk in the present.

3.3. Setting and Discussion about Monte Carlo Simulation

3.3.1. Data and Estimated GBM Parameters

While Chapter 4, 5, and 6 assume different numbers of energy markets as the source of energy price risk, the common dataset is utilized to estimate parameters for the GBM model in those chapters.

For imported fossil fuels, yearly price data is obtained from EDMC Handbook of Energy and Economic database in Japan during the period 1971–2005 [1]. Six types of fossil fuels are chosen as sources of the energy price risk: coal, crude oil, natural gas, naphtha, LPG, and heavy oil. Table 3.1 lists the drift parameter, the volatility parameter, and the initial price level of the types of imported fossil fuels, and Table 3.2 presents the correlation coefficients among them.

For CO_2, the daily price data of the European Climate Exchange (ECX) [92][5]

[5] We chose ECX as a proxy for the Japanese CO_2 market because ECX is the largest market in the EU-ETS, which occupied 73% of the world CO_2 market volume in 2009 [92]. Because ECX is a

Table 3.1 Drift parameter, volatility parameter, and the initial price level of types of imported energy.

	coal	crude oil	natural gas	naphtha	LPG	heavy oil
Drift	−0.02	0.039	0.012	0.032	0.022	0.033
Volatility	0.194	0.314	0.231	0.317	0.278	0.318

Table 3.2 Correlation coefficients among the types of imported energy.

	Coal	Crude oil	Natural Gas	Naphtha	LPG	Heavy oil
coal	1					
crude oil	0.645	1				
natural gas	0.728	0.913	1			
naphtha	0.6	0.944	0.842	1		
LPG	0.658	0.936	0.923	0.9	1	
heavy oil	0.589	0.971	0.844	0.941	0.875	1

new market, the immaturity of the market and mistakes by governments can influence the market price. This problem will be improved as the market continues and more data becomes available.

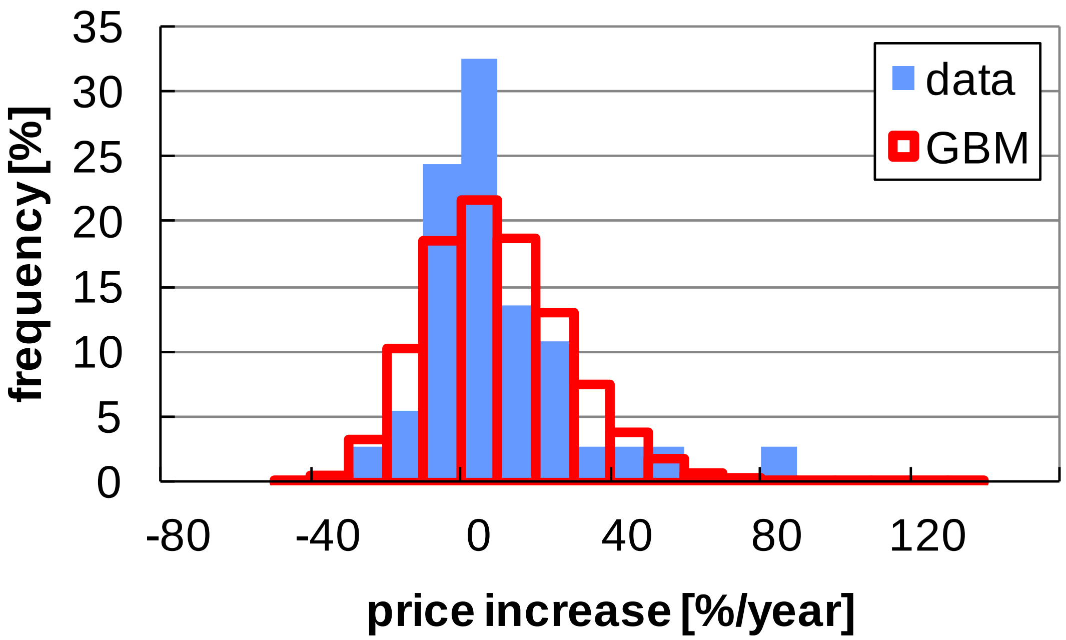
is utilized for estimating parameters because the Japanese CO_2 market is still in an experimental stage, and there is no enough length of yearly time series data. The volatility parameter for the yearly change is estimated by multiplying that for the daily change by the root of the number of business day in the market [84]. The estimated drift and volatility parameters for the CO_2 price are –0.0447 and 0.446, respectively. Note that the correlation coefficients between the prices of fossil fuels and CO_2 are arbitrarily set to zero because there is no sufficiently long time series data for the price of CO_2.

The price of coal has the smallest drift and volatility parameters and the price of natural gas has the second smallest drift and volatility parameters. The result indicates that crude oil and oil products have higher energy price risk than coal and natural gas. Among the prices of oil products, that of LPG has relatively smaller drift and volatility parameters indicating that LPG has smaller energy price risk than other oil products. The correlation coefficients between the price of coal and non-coal energies are relatively smaller than those among the prices of non-coal energies. The correlation coefficients among crude oil and oil products are necessarily higher than those between coal and oil and between natural gas and oil. Those results indicate that substituting crude oil and oil products with coal and natural gas can decrease the energy price risk. Substituting with coal, in particular, can decrease the risk more significantly than natural gas as long as there is no carbon emission cost.

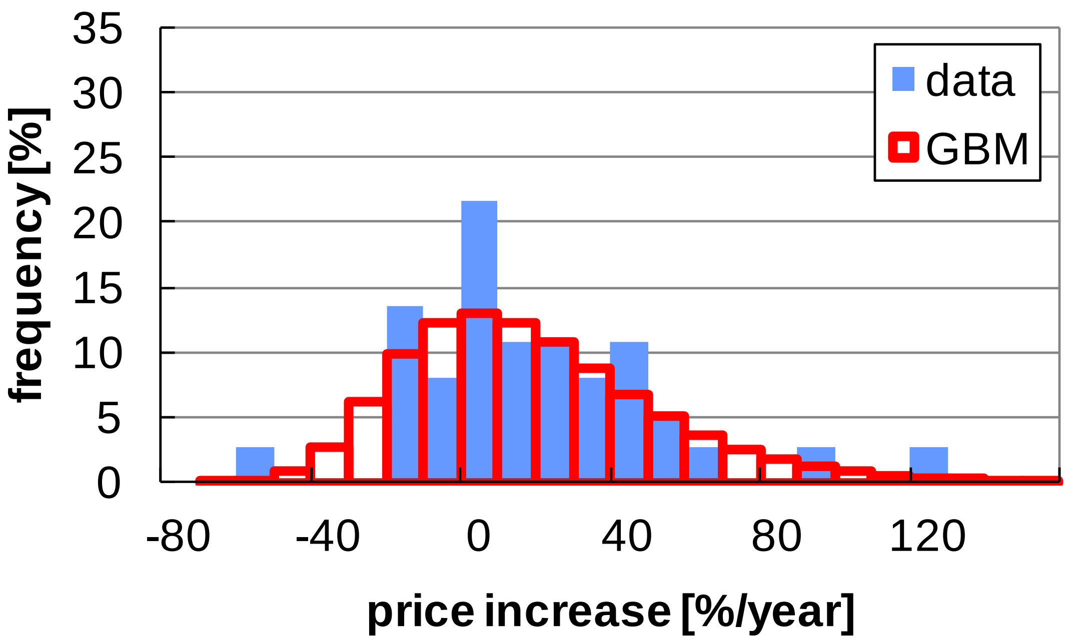
The price of CO_2 has larger volatility parameter and smaller drift parameter than the prices of all six fossil fuels. The result indicates that the price of CO_2 has larger risk of price increase than fossil fuels while it has a downward trend in the present. In terms of environmental load, coal has the largest CO_2 emission intensity, and natural gas has the smallest one: the CO_2 emission intensity of coal, crude oil, and natural gas are 3.96, 3.07, and 2.35 $MtCO_2$/MTOE, respectively [1]. Then, coal will be substituted with oil and natural gas to decrease the energy price risk if high level of carbon cost coordinated with market prices is imposed on CO_2 emission.

3.3.2. Data and Estimated GBM Parameters

Figure 3.2 and 3.3 presents distribution in the prices of fossil fuels and CO_2 based on the actual data and Monte Carlo simulation, respectively. The number of iterations for the Monte Carlo simulation is set as 100,000. For the price of CO_2, only the estimated results are presented because there is no actual data for yearly CO_2 price as long as that of fossil fuels. The results from Monte Carlo simulation roughly succeed in representing characteristics of actual data. In the both actual and

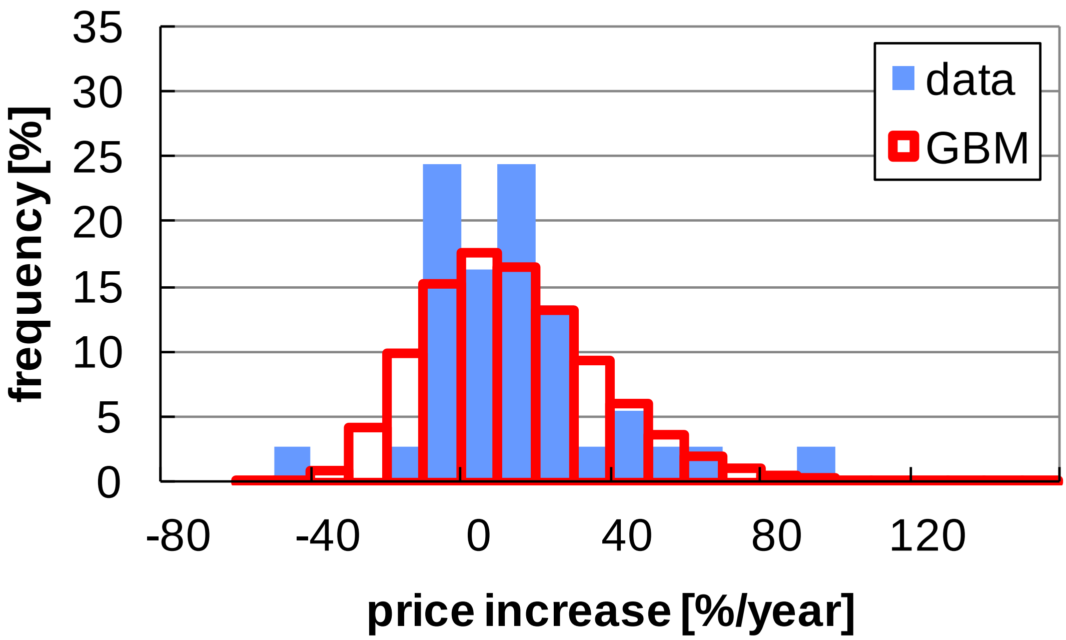


(a) price distribution of imported coal

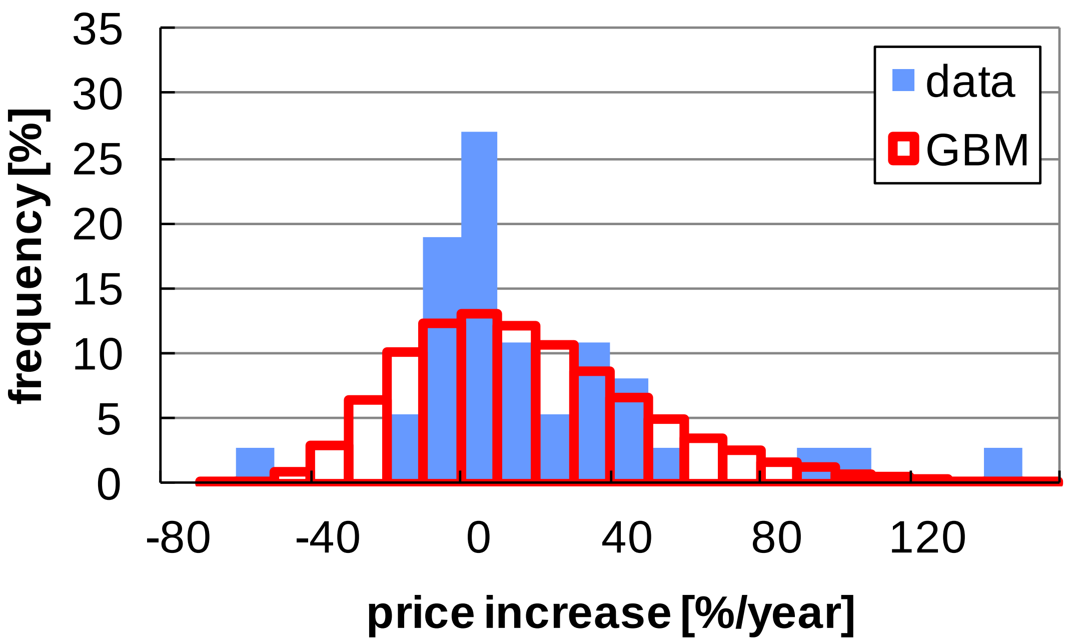


(b) price distribution of imported oil

Figure 3.2 Distributions in the prices of six imported fossil fuels based on actual data and Monte Carlo simulation. Bars painted by blue and framed by red line present actual data and estimated results, respectively.

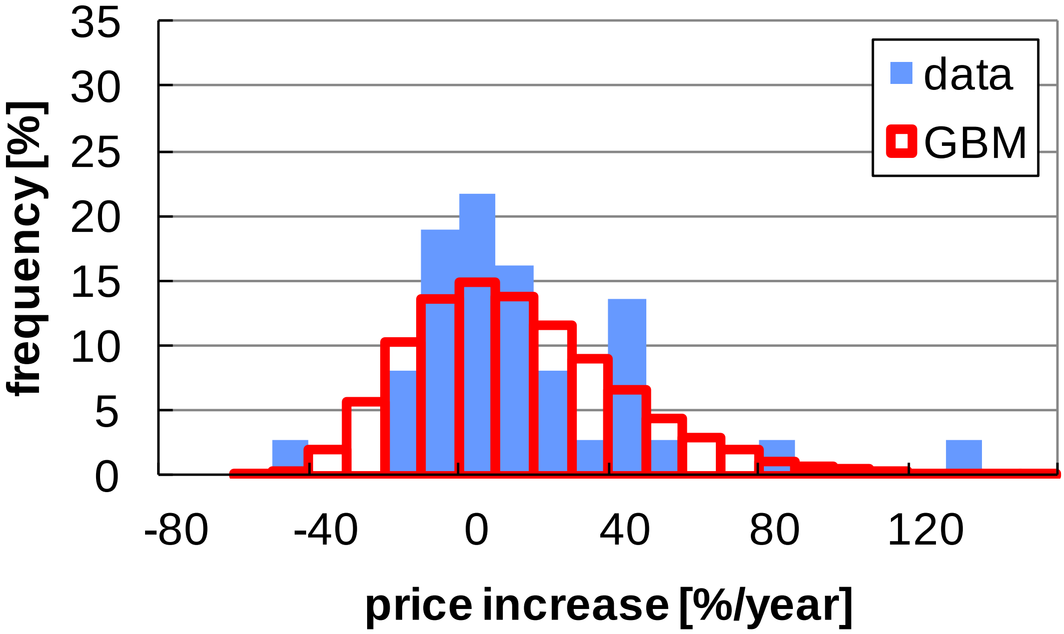


(c) price distribution of imported natural gas

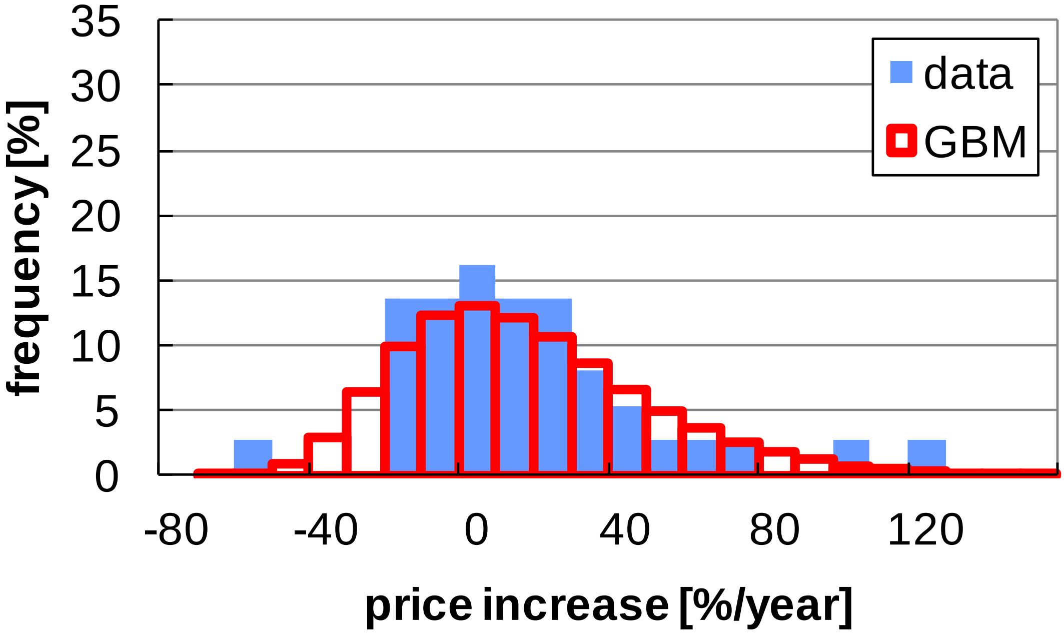


(d) price distribution of imported naphtha

Figure 3.2 (continued)



(e) price distribution of imported LPG



(f) price distribution of imported heavy oil

Figure 3.2 (continued)

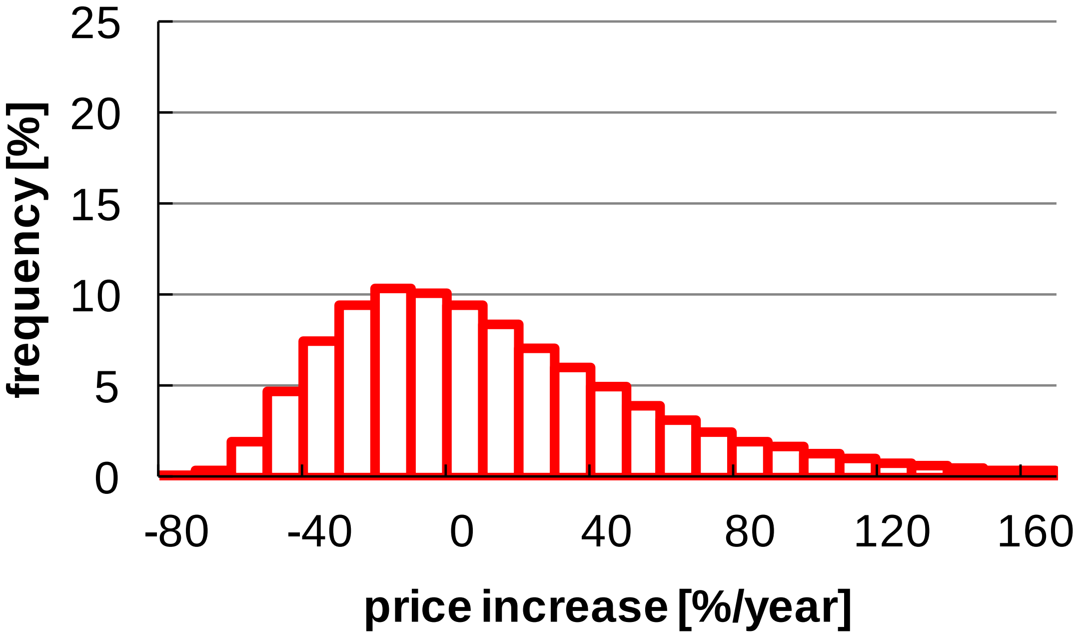


Figure 3.3 Distributions in the prices of CO_2 based on actual data and Monte Carlo simulation. Only the estimated results are presented because there is no actual data for yearly CO_2 price as long as that of fossil fuels.

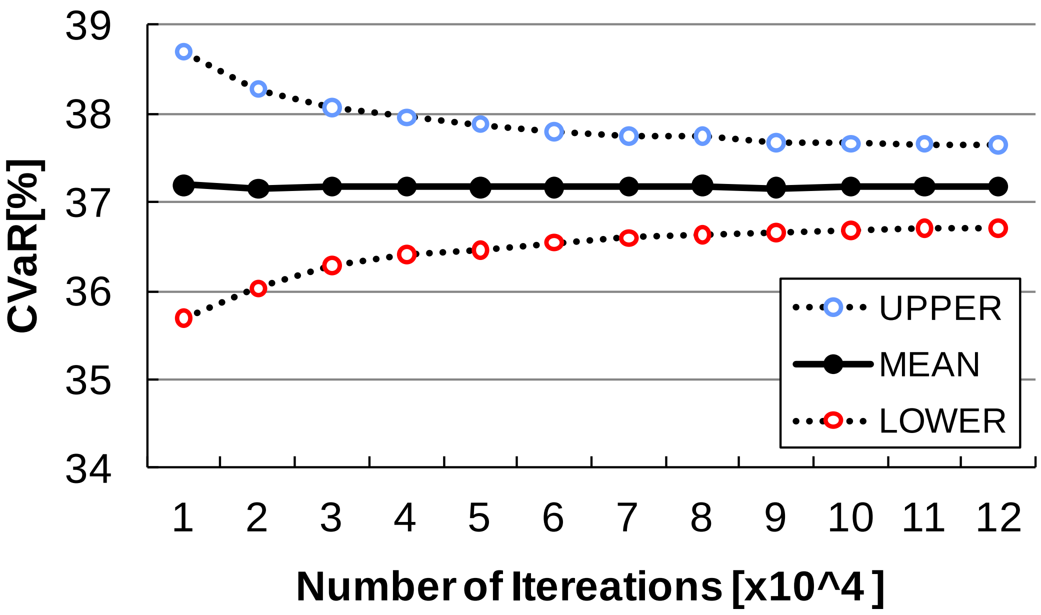
estimated distribution, the price of coal has the highest peak of frequency around zero, the price of oil has the lowest, and the price of natural gas has the medial height of peak. The prices of oil products have long upper tail, indicating high energy price risk, as crude oil. Those results indicate that the GBM can roughly approximate the actual price distribution of imported fossil fuels.

However, there are two differences between the actual and estimated distributions. First, the actual data has rugged shape different from estimated probabilistic distribution. Except for the price distributions of coal and heavy oil, the frequency does not simply decrease as the size of price change increase; they have two or more peaks. On the other hand, probabilistic density estimated by the GBM is “smoothed” and is simply decreases as the size of price change increase. Second, the actual data has longer upper tails than estimated distributions. Especially, the prices of crude oil and oil products experienced price increases larger than 100% per year. However, according to the estimated probabilistic distribution, such a size of price increases much less frequently occurs than the actual distributions. When focusing on the risk of extreme price increase, the second difference becomes more important. While this study applies the GBM for the prices of fossil fuels by the reasons discussed in 3.3.1, the introduction of a model that can describe longer upper tail needs to be continuously discussed in the future works.

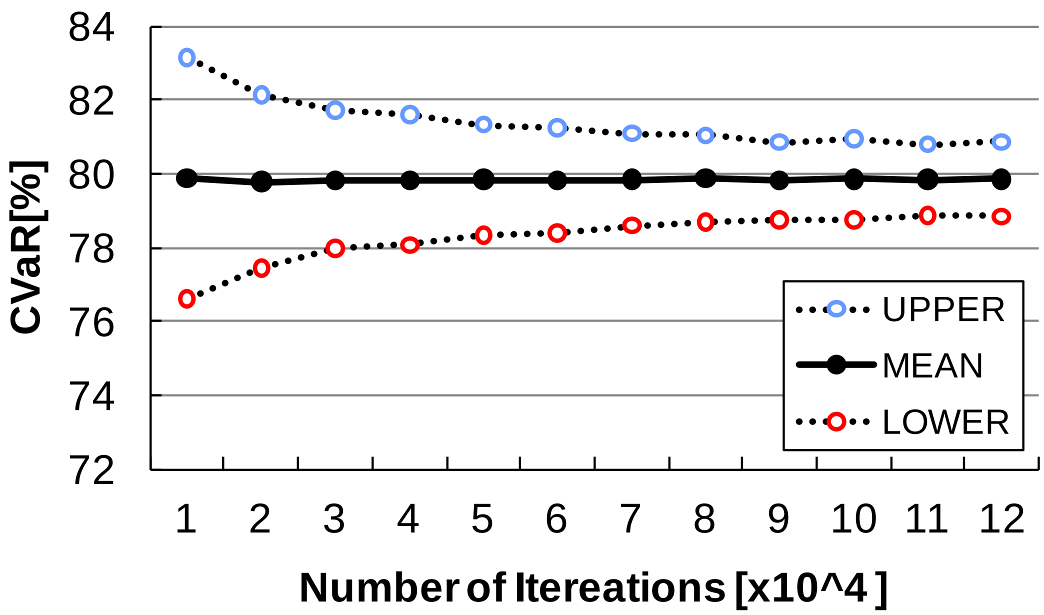
3.3.3. CVaR and Error in Prices of Fossil Fuels and CO_2

This subsection verifies how many numbers of iterations are required for the stable results of the Monte Carlo simulation in the I–O portfolio model. There are three steps to quantify the size of error. First, the CVaR in the prices of fossil fuels and CO_2 are repeatedly estimated by the Monte Carlo simulation. The number of iterations is varied from 10,000 to 120,000 at 10,000 intervals, and 500 sets of simulations are repeated for each number of iterations. Second, the mean and valiance in the results, i.e. the CVaR, is calculated from the 500 sets of simulations for each number of iterations. Third, the size of error is estimated as the ratio between the value of mean and six-folded sigma. The value of confidence level, β, is also varied to investigate an influence on the size of error.

Figure 3.4, 3.5, and 3.6 present the mean and error of the CVaR in the prices of six fossil fuels calculated from the 500 sets of Monte Carlo simulations with β = 90%, 95%, and 99%, respectively, and Figure 3.7 presents the mean and error of CVaR in the prices of CO_2 calculated as the same manner. “MEAN” presents a simple average in the results of 500 sets of simulations. “UPPER” and “LOWER”, indicating the size of

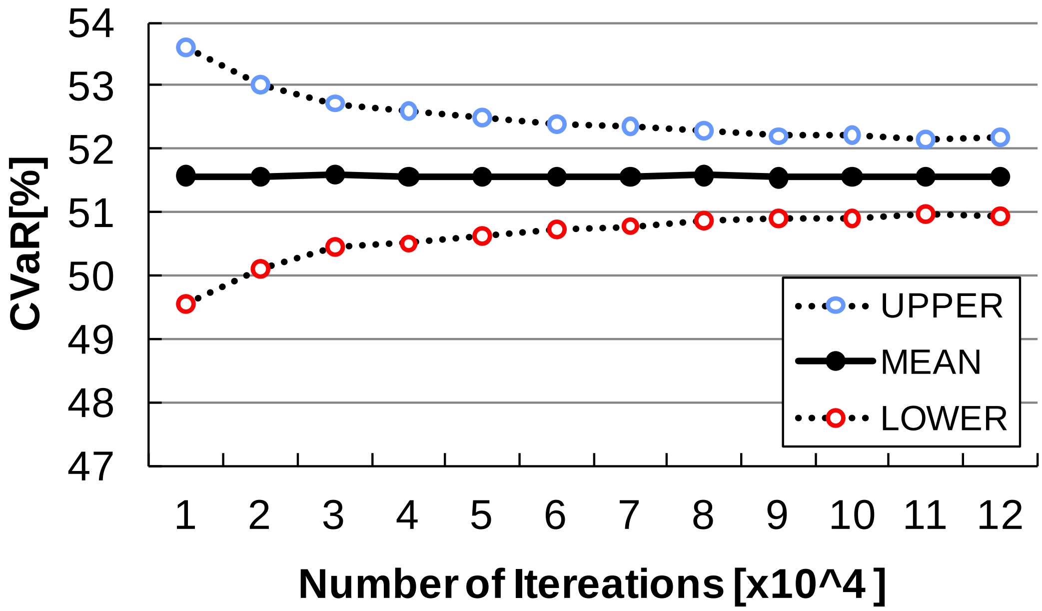


(a) CVaR in imported coal

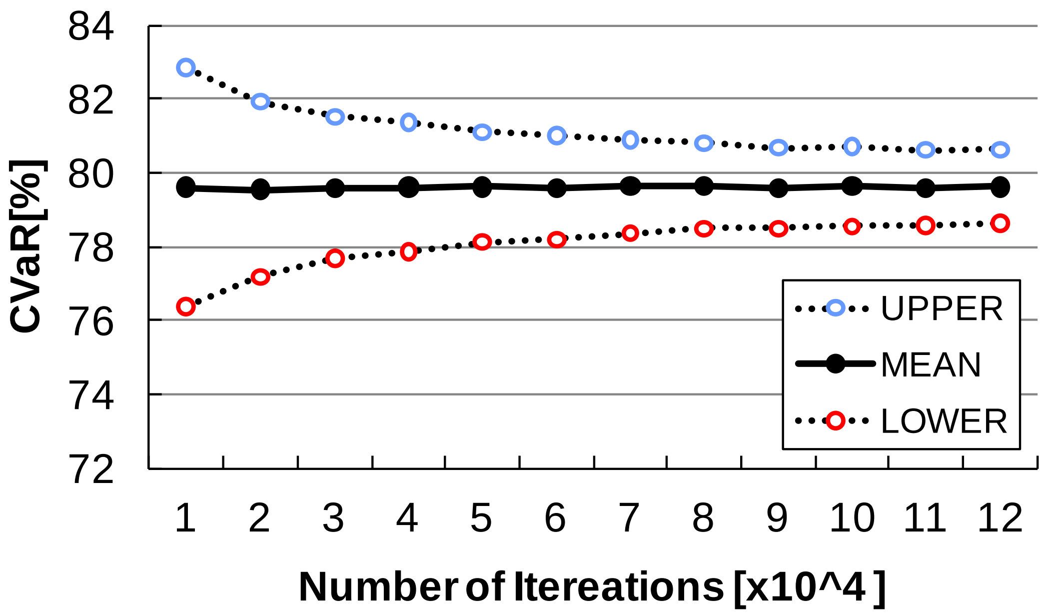


(b) CVaR in imported crude oil

Figure 3.4 Estimated value and error of CVaR in the prices of six fossil fuels. The value of β is 90%. “MEAN” presents a simple average in the results of 500 sets of Monte Carlo simulation. “UPPER” and “LOWER” presents the value MEAN plus and minus tripled standard deviation. The standard deviation is also estimated from the results of 500 sets of Monte Carlo simulations.

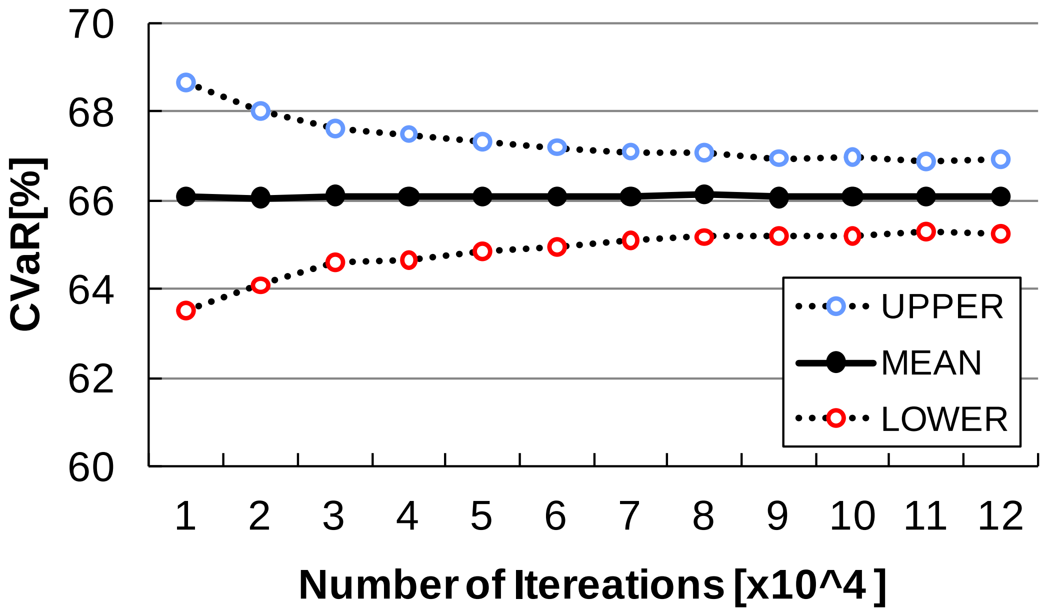


(c) CVaR in imported natural gas

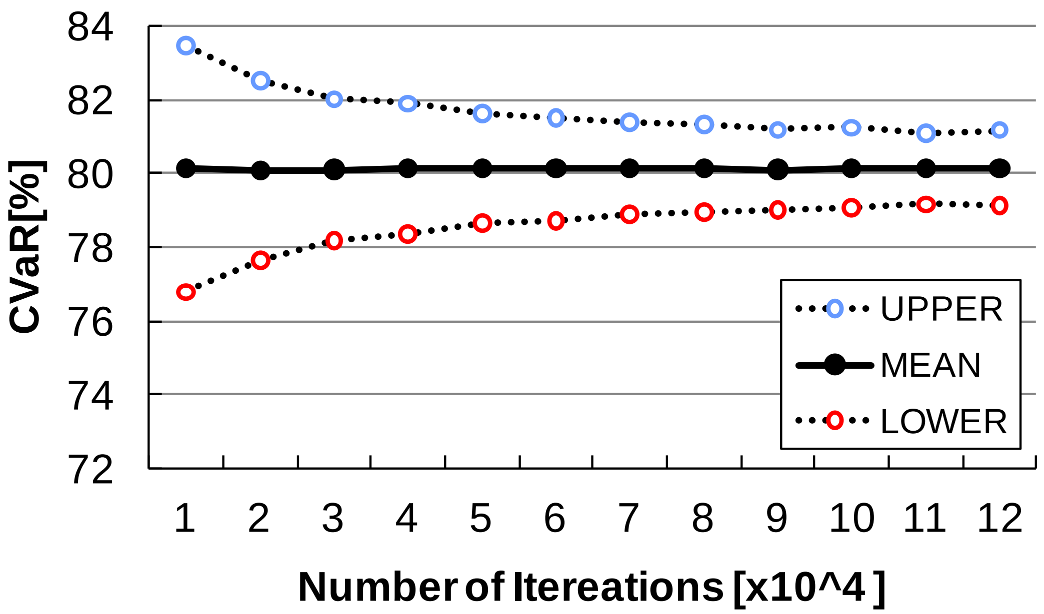


(d) CVaR in imported naphtha

Figure 3.4 (Continued)

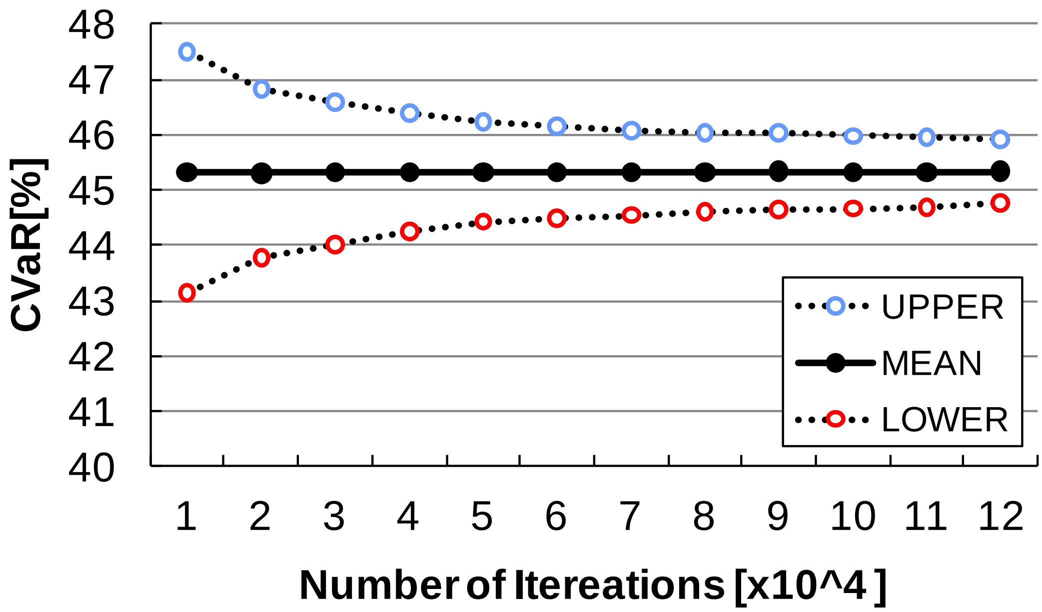


(e) CVaR in imported LPG

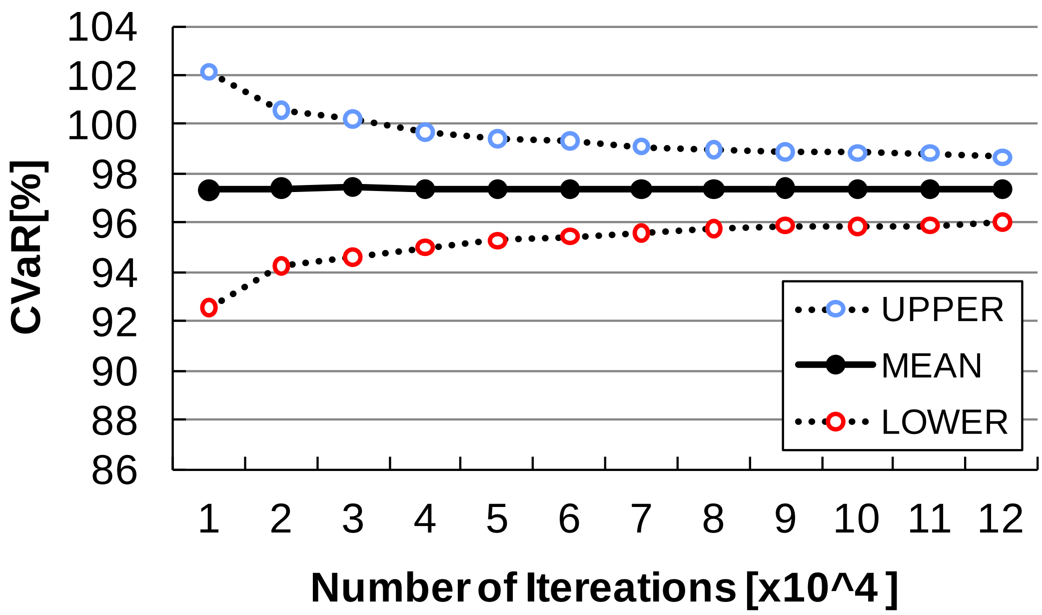


(f) CVaR in imported heavy oil

Figure 3.4 (Continued)

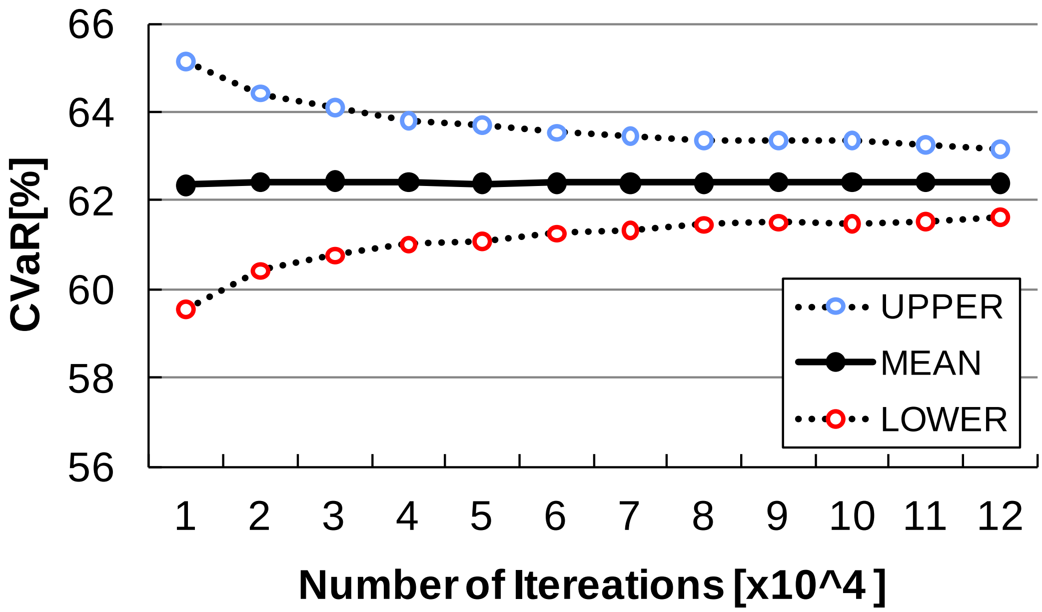


(a) CVaR in imported coal

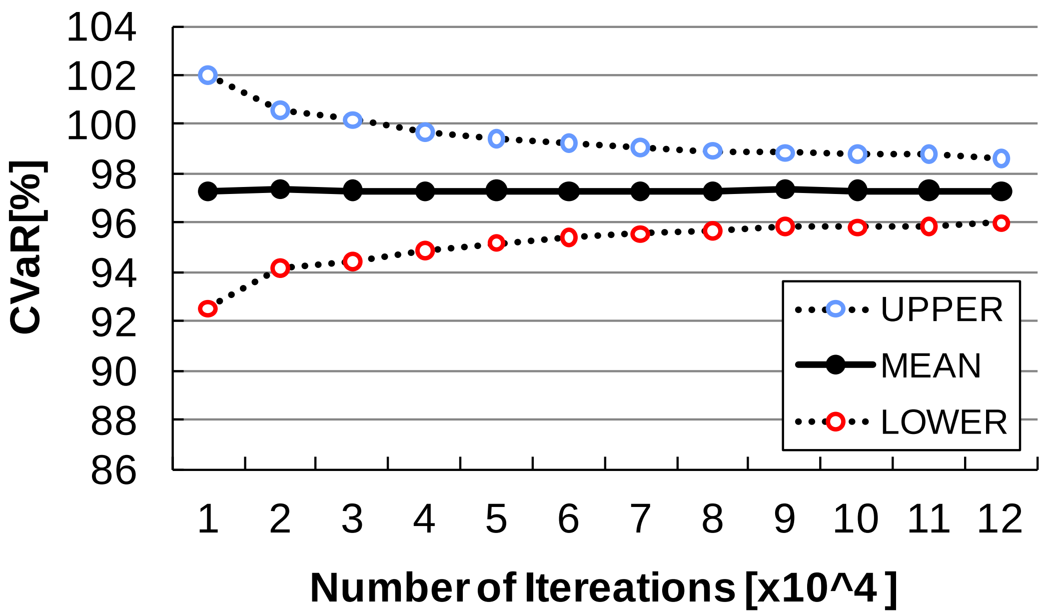


(b) CVaR in imported crude oil

Figure 3.5 Estimated value and error of CVaR in the prices of six fossil fuels. The value of β is 95%. “MEAN” presents a simple average in the results of 500 sets of Monte Carlo simulation. “UPPER” and “LOWER” presents the value MEAN plus and minus tripled standard deviation. The standard deviation is also estimated from the results of 500 sets of Monte Carlo simulations.

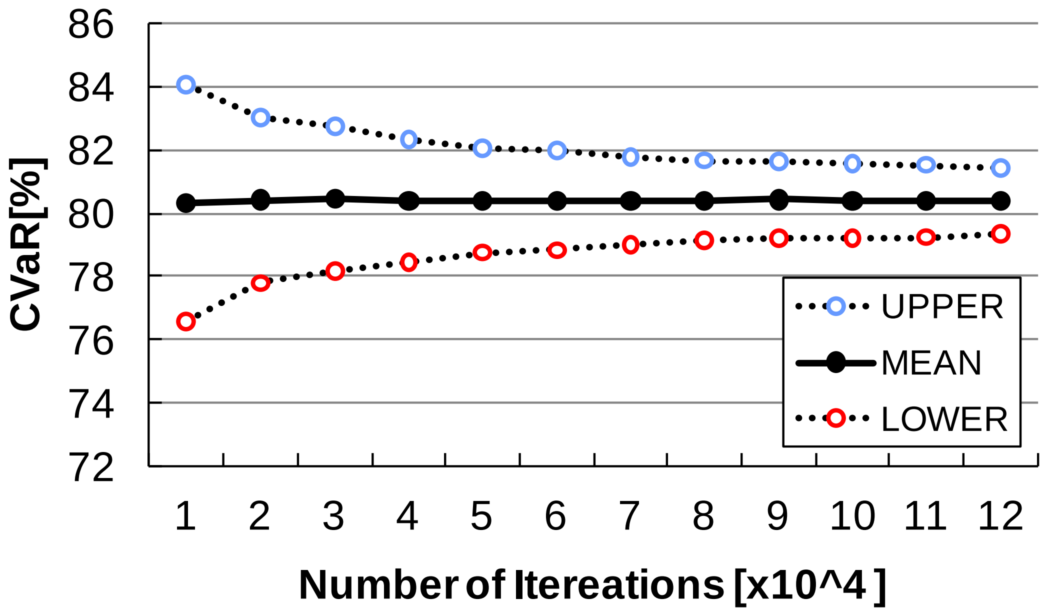


(c) CVaR in imported natural gas

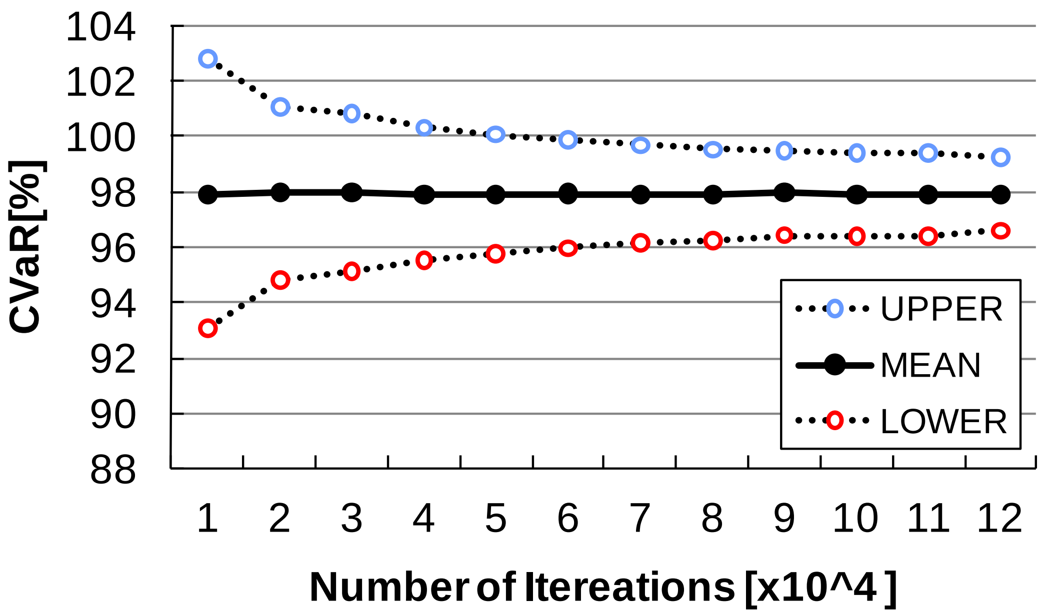


(d) CVaR in imported naphtha

Figure 3.5 (continued)

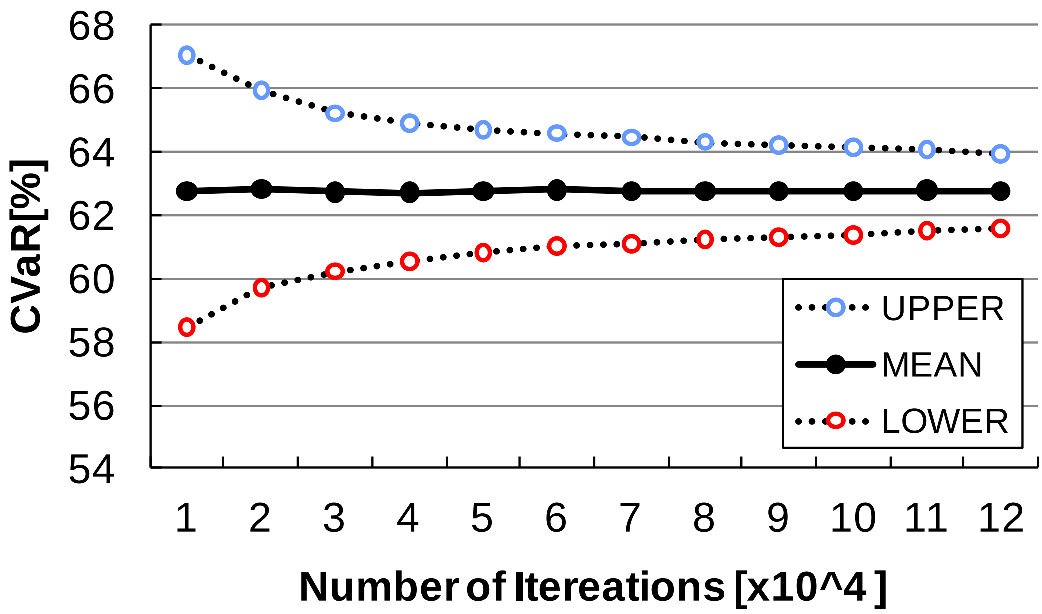


(e) CVaR in imported LPG

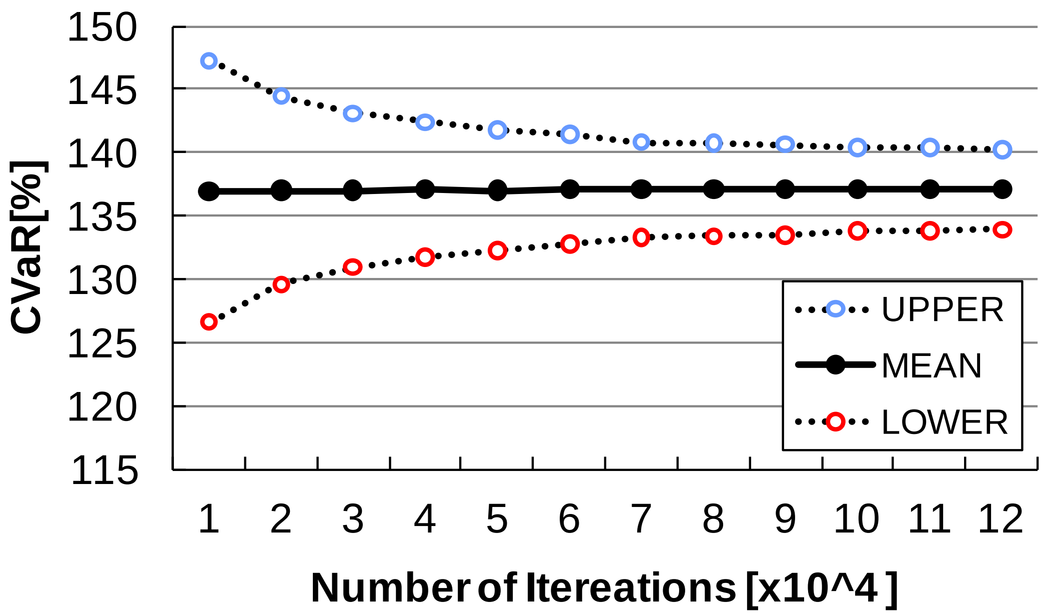


(f) CVaR in imported heavy oil

Figure 3.5 (continued)

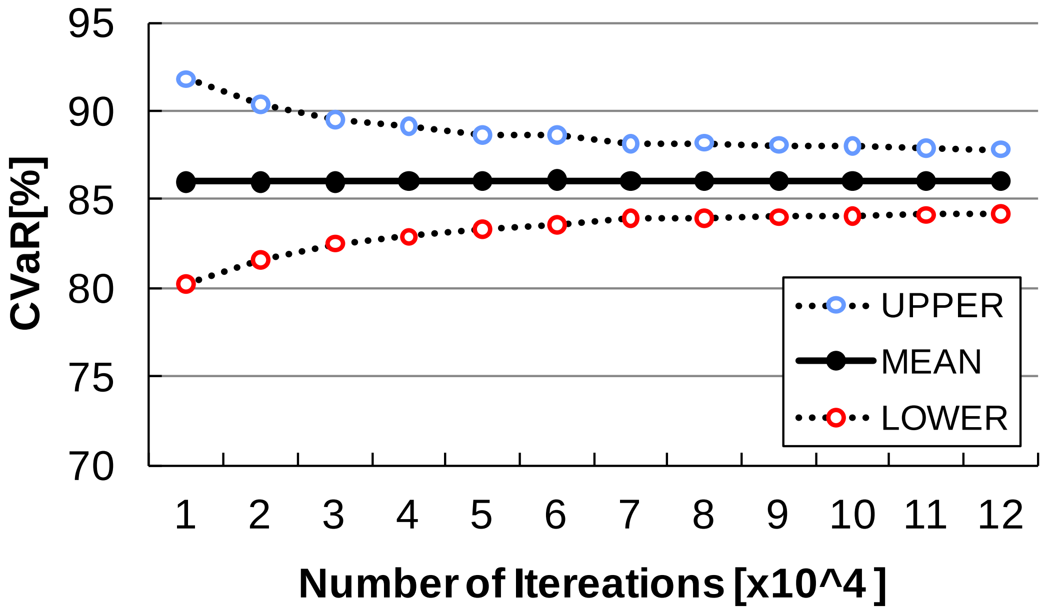


(a) CVaR in imported coal

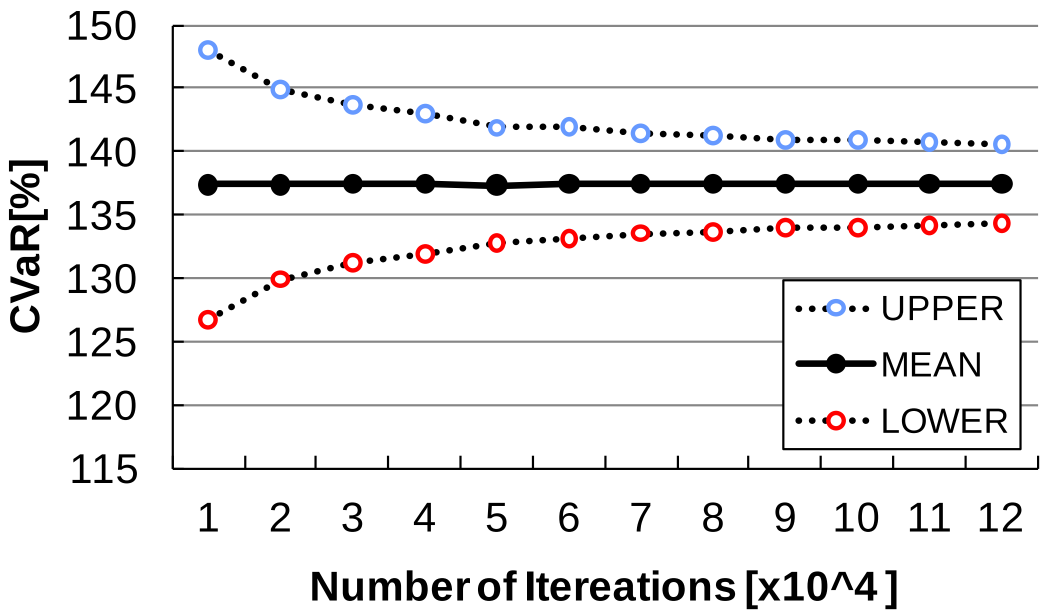


(b) CVaR in imported crude oil

Figure 3.6 Estimated mean and error of CVaR in the prices of six fossil fuels. The value of β is 99%. “MEAN” presents a simple average in the results of 500 sets of Monte Carlo simulation. “UPPER” and “LOWER” presents the value MEAN plus and minus tripled standard deviation. The standard deviation is also estimated from the results of 500 sets of Monte Carlo simulations.

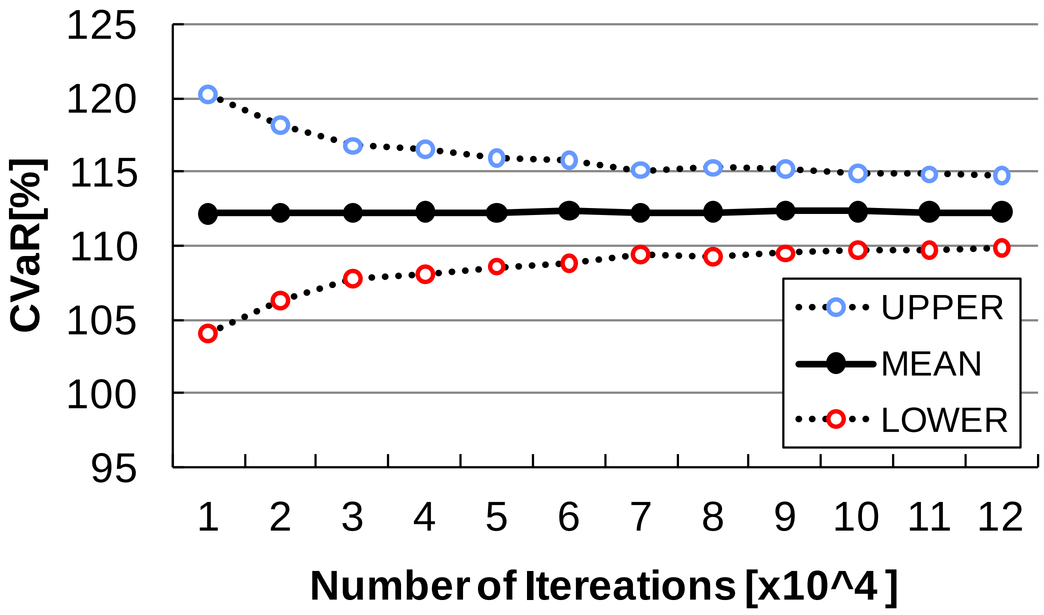


(c) CVaR in imported natural gas

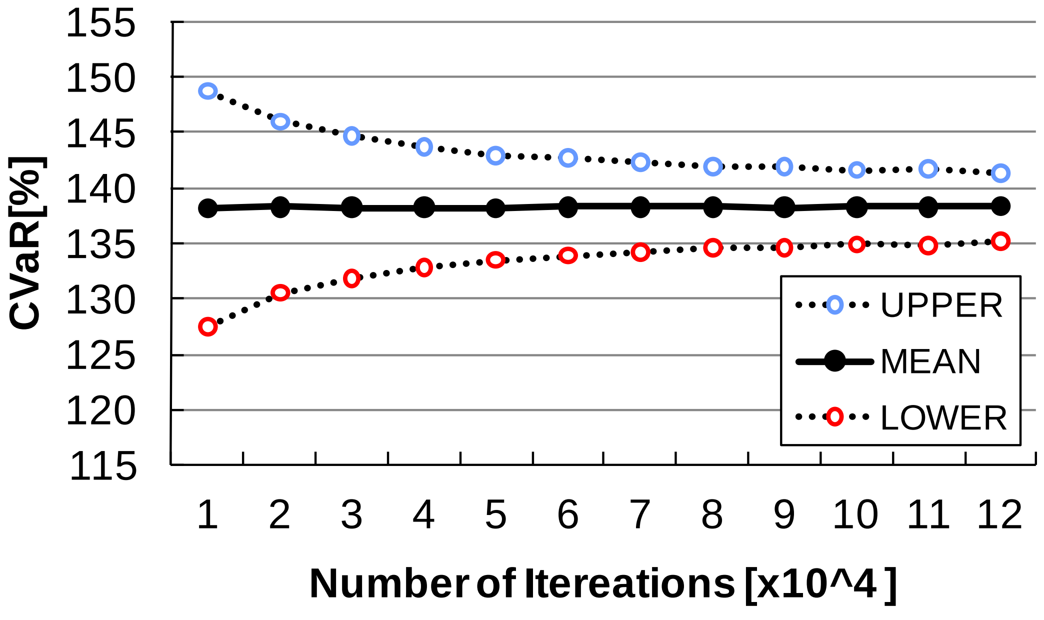


(d) CVaR in imported naphtha

Figure 3.6 (continued)

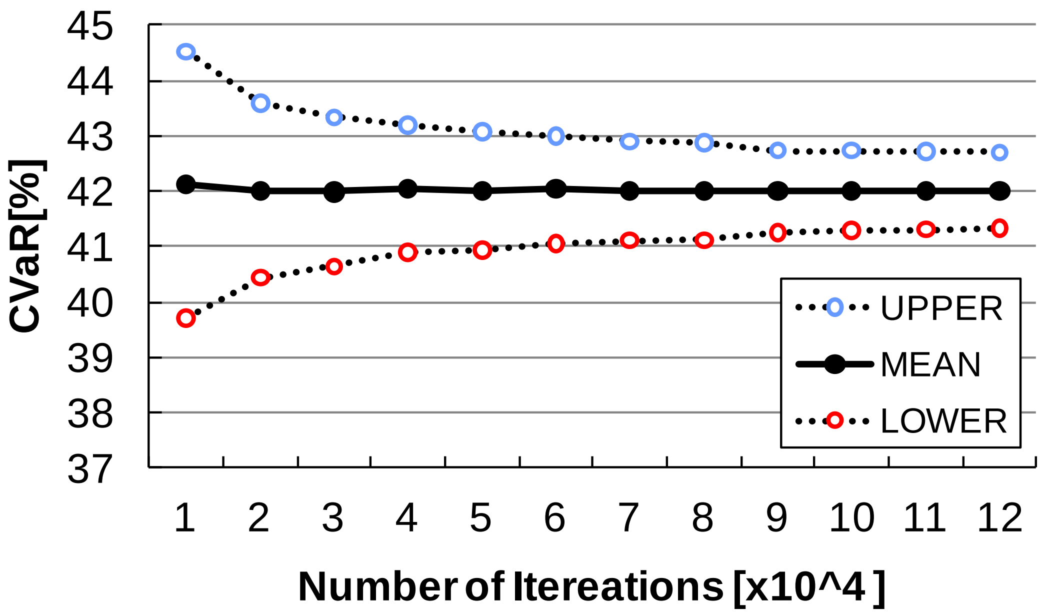


(e) CVaR in imported LPG

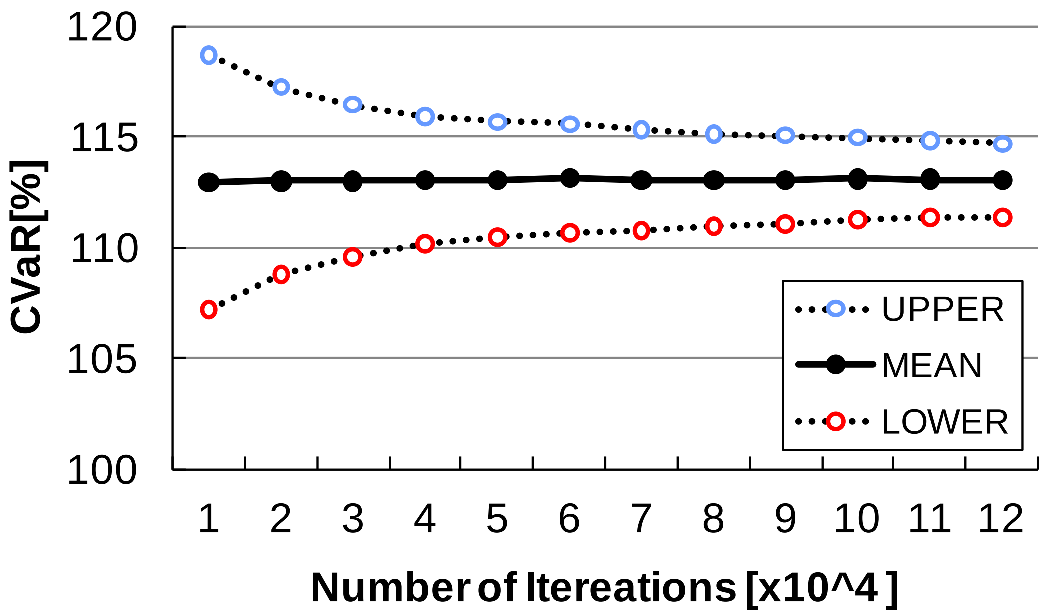


(f) CVaR in imported heavy oil

Figure 3.6 (continued)

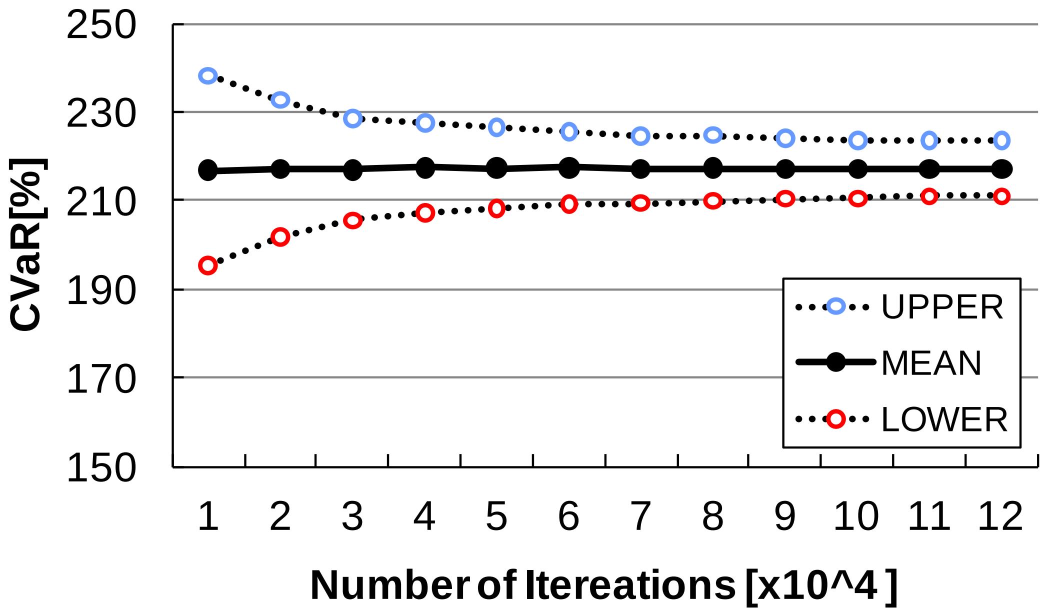


(a) CVaR in price of CO2, β = 90%



(b) CVaR in price of CO2, β = 95%

Figure 3.7 Estimated mean and error of CVaR in the prices of CO_2. "MEAN" presents a simple average in the results of 500 sets of Monte Carlo simulation. "UPPER" and "LOWER" presents the value MEAN plus and minus tripled standard deviation. The standard deviation is also estimated from the results of 500 sets of Monte Carlo simulation.



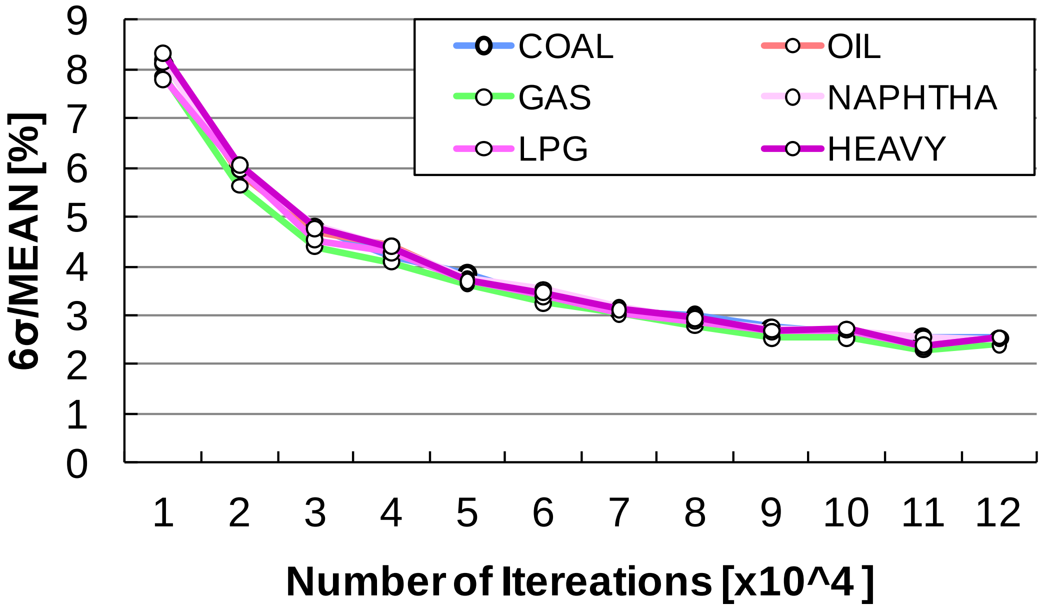
(c) CVaR in price of CO2, β = 99%

Figure 3.7 (Continued)

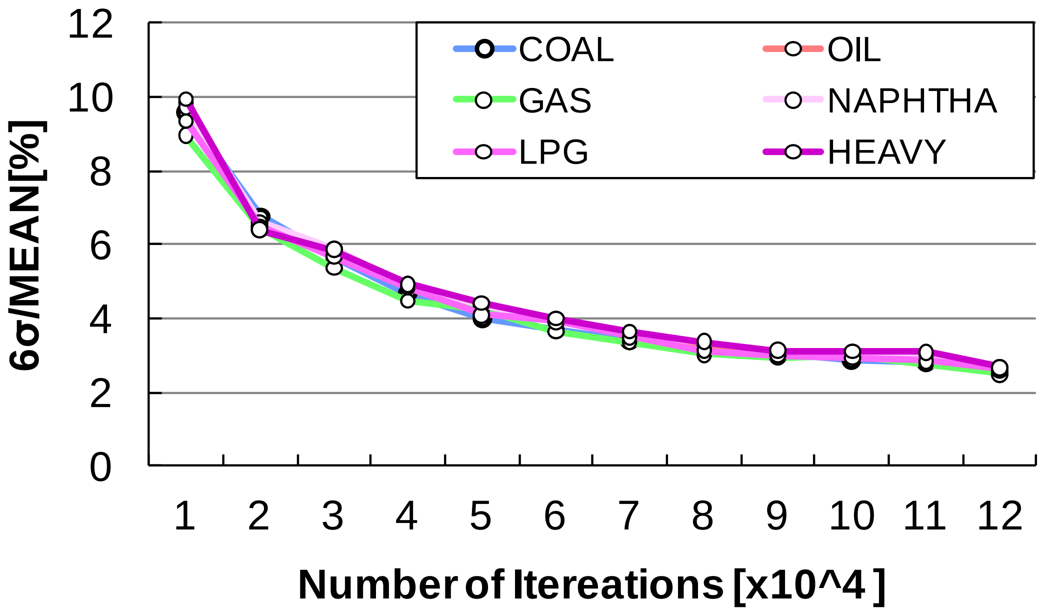
error, present the value MEAN plus and minus tripled standard deviation. The standard deviation is also estimated from the results of 500 sets of Monte Carlo simulation. By definition, the value of CVaR increases as β increases; the larger β indicates that only the more extreme price increases are utilized to calculate the CVaR. Regardless of the value of β, the standard deviation in the CVaR decreases as the number of iterations in one set of Monte Carlo simulation increases, and is almost converged as the number of iteration reached to 120,000.

Figure 3.8 and 3.9 presents the ratio between the mean and six-folded sigma for fossil fuels and CO_2, respectively. The result of Monte Carlo simulations has smaller deviation from the mean than this ratio by the probability of 99.7%, i.e. ±3σ. For the prices of fossil fuels, the ratio is 2.5–2.7%, 2.9–3.1%, and 4.4–5.0% when the number of iteration is 100,000 and β is 90%, 95%, and 99%, respectively. For the price of CO_2, the ratio is 3.4%, 3.3%, and 6.1%, respectively. Those results indicate that there is a tradeoff between the confidence level of CVaR and the accuracy of Monte Carlo simulation; the confidence level of CVaR needs to be lowered to decrease the error in the results of Monte Carlo simulation. This dissertation set the number of iteration per set of Monte Carlo simulation 100,000, and set β 95%, respectively, because the size of error is almost converged after the number of iterations exceeds 100,000. As a result, value of CVaR indicates an extreme increase in the prices that the markets experience once per 20 (=100/(100 – β)) year, and the size of error is 2.9–3.1% for the prices of fossil fuels, and 3.3% for the price of CO_2, respectively.

In addition, the reliability in the value of energy price risk depends on whether the sector locates in the upstream or downstream of the production chains in the domestic industry. Although the I–O analysis assumes that input coefficients express actual input–output relationship among the sectors, statistical surveys for constructing an I–O table must include some errors, and the level of error cannot be verified because of social cost for survey. If we assume that every input coefficient has the same level of error, the level of error in an energy price risk is in proportion to the number of input coefficients utilized to estimate the index of risk. In other words, the sectors located in the downstream part of the structure, such as the assembly, commerce, and household sectors, have larger error than the sectors located in the upstream part of the structure. For the reason, we should not make political proposal based on a policy implication obtained from a single analytical result, especially the result that include “potential” error such as the error in input coefficients. We need to compare several policy implications obtained from several studies utilizing different methods and data, and then pick up common implications from those studies for practical use. From the viewpoint, this dissertation can provide the analytical framework and empirical results based on new and developed standpoints in comparison with earlier studies and can contribute to the field of energy policy.

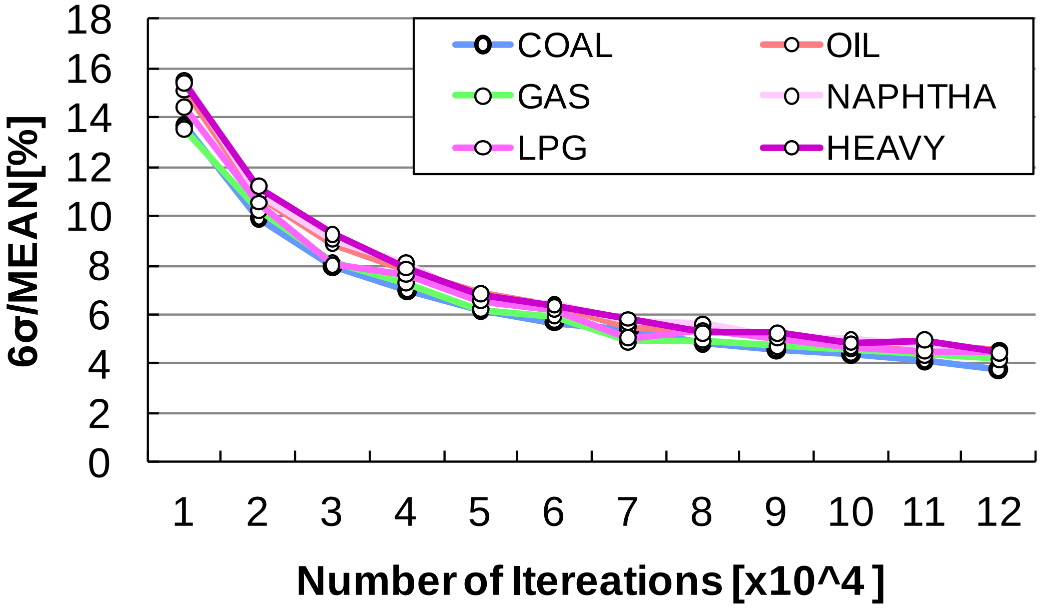


(a) β = 90%



(b) β = 95%

Figure 3.8 Ratio between the mean and six-folded sigma of the CVaR in the prices of fossil fuels. The result of Monte Carlo simulation has smaller deviation from the mean than this ratio by the probability of 99.7%, i.e. ±3σ.



(c) β = 99%

Figure 3.8 (continued)

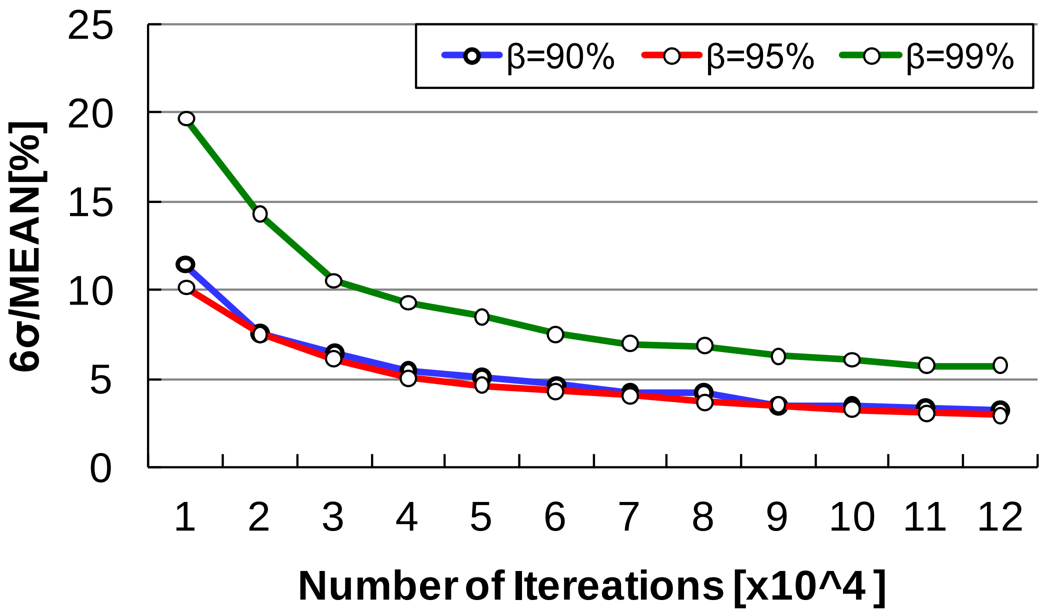


Figure 3.9 Ratio between the mean and six-folded sigma of the CVaR in the prices of CO_2. The result of Monte Carlo simulation has smaller deviation from the mean than this ratio by the probability of 99.7%, i.e. ±3σ.

Chapter 4

Analyzing Demand-Side Portfolio

4.1. Motivation

The emissions trading system increases uncertainty in the producer prices of both the electricity generation sector and non-energy sectors because the cost of carbon emissions, which fluctuates in free markets, is added to the cost of electricity generation. More than 60% of electricity has been generated from fossil fuels during the last decade [01], and the emissions trading system has been experimentally introduced [05] for the preparation of its full-scale implementation in Japan. Therefore, the Japanese electricity generation sector needs to mitigate the risk of increase in the prices of carbon as well as those of fossil fuels.

For the mitigation of the energy price risk, contribution of the short-term portfolio selection needs to be examined. Although there are many earlier studies dealing with portfolio selection from the long-term perspective, short-term portfolio selection is another perspective. Portfolio selection from the long-term perspective suggests the selection of the electricity generation mix by installing new power plants, while that from the short-term perspective suggests the selection by changing the utilization of existing capacities without installing new capacities [09]. If the electricity generation sector has idle capacity, the generation portfolio can be changed without installing new power plants. Several studies focus on portfolio selection from the short-term perspective. Söderholm [85] analyzed the role of fuel flexibility in the West European electricity generation sector by using the aggregated data of eight countries. By estimating cross-price elasticities between oil and natural gas power generation, the study found that oil and gas power generation are substituted for each other when the price of one of these fuels rises. The study also showed that the magnitudes of the cross-price elasticities are fairly closely related to the corresponding shares of multi-fired capacity. In contrast, Tauchmann [86] showed that there is no evidence supporting the hypothesis that fuel-mix decisions are determined by prices of fossil fuels in Germany. According to [85], Germany has relatively smaller multi-fired capacity (33% of total generation capacity in 1996). This seems to result in the weak relationship between the generating mix and the prices of fossil fuels.

Although the Japanese electricity generation sector has low multi-fired capacity, it has abundant idle capacity. In Japan, the average capacity factor in fossil fuel-fired power plants was 43.4% in 2005; those in coal-, oil-, and gas-fired plants were 75.3%, 18.9%, and 47.8%, respectively [87]. This large quantity of idle capacity results from past energy policies that required electricity companies to substitute oil with other fossil fuels and nuclear fuel. This capacity can be used to lower fuel costs by changing the generation mix in response to changes in the prices of fossil fuels and CO_2.

This chapter examines whether the short-term portfolio selection by the electricity generation sector can decrease the risk of energy cost volatility in the energy and non-energy sectors in Japan. The I–O portfolio analysis is revised for this purpose; the network flow model is newly introduced to consider the change in the generation mix in response to the energy and CO_2 prices. The risk index of energy cost volatility is estimated through a Monte Carlo simulation. The four scenarios with different CO_2 price levels are prepared to clarify an influence of the level of CO_2 price on the energy price risk.

4.2. Methodological Developments

4.2.1. Network Flow Model of Electricity Generation

As the prices of fossil fuels and CO_2 change, the electricity generation mix minimizing the running cost also changes. In this dissertation, we assume four rules that restrict the change in the generation mix of the electricity generation sector corresponding to the price changes. First, the electricity generation sector always tries to minimize the running cost of electricity generation. Second, the electricity generation sector can change only the share of fossil fuel-fired plants because non-fossil fuel-fired plants are utilized as base-load power plants. Third, the electricity generation sector cannot increase the generation capacity, and can change only the generation mix under the restriction of the existing generation capacity. The generation capacity has increased by only 0.5% per year since 2005 [01] because the electricity demand has seldom increased. Furthermore, we can ignore the change in generation capacity as we focus on the influence of change in the generation mix. Fourth, the energy efficiency of a generation plant is constant regardless of the change in its capacity factor. Under those assumptions, generation mix selection can be represented by the generalized minimum cost flow (GMCF) model [88] as follows

$$\text{Min} \quad \sum_{j=1}^{A} q(a_j)\mathrm{f}(a_j) \tag{4-1}$$

$$\text{s.t.} \sum_{a_j \in \delta^+ v_i} f(a_j) - \sum_{a_j \in \delta^- v_i} \alpha(a_j) f(a_j) = 0 \quad \text{for } 2 < i < V-1 \tag{4-2}$$

$$\sum_{a_j \in \delta^- v_V} \alpha(a_j) f(a_j) = D \tag{4-3}$$

$$c_1(a_i) \le f(a_i) \le c_2(a_i) . \tag{4-4}$$

For the structure of the model, v_i and a_j denote a node and an arc on the network, respectively, V and A denote the number of nodes and arcs, v_1 and v_V denotes the start and the end node of the network, $\delta+v_i$ and $\delta-v_i$ denote a set of arcs that start from and end with node v_i, respectively. In this study, each node indicates each type of energy flow, and each arc indicates each type of process, i.e., an import or an electricity generation process. Then, v_1 and v_V indicate the input and output of the GMCF model, i.e., a set of all import sources of energy and the electricity generated by fossil fuel fired plants, respectively.

For arcs indicating the import process, $c_1(a_j)$ and $c_2(a_j)$ indicate the lower and upper capacity of imports, respectively, $\alpha(a_j)$ indicates loss in the import process, and $q(a_j)$ indicates the import prices of fossil fuels. For each iteration of the Monte Carlo simulation, q_i' (1), calculated by the equation (3-6), is substituted to $q(a_j)$. For arcs indicating the electricity generation process, $c_1(a_j)$ and $c_2(a_j)$ indicate the lower and upper capacity of electricity generation, respectively, $\alpha(a_j)$ indicates generation efficiency, and $q(a_j)$ indicates the variable O&M cost for electricity generation.

The constraint (4-2) indicates the balance of energy flow on each node except for the start and end points of the network. The constraint (4-3) indicates the balance of energy flow at the end point of the network; the electricity generated by fossil fuel-fired plants must satisfy the demand for electricity produced by fossil fuel-fired plants, D. The constraint (4-4) indicates the lower and upper limitations of the energy flow in each process. The conceptual figure of the model is represented by Figure 4.1, and the meanings of the parameters are summarized by Table 4.1. By solving the GMCF problem represented by (4-1)–(4-4), the energy flows in each arc are obtained, and the quantities of electricity generated by each type of plant are obtained as the amounts of energy flows passing through arcs corresponding to each type of plant.

4.2.2. Procedure of Analysis

The revised version of I−O portfolio analysis consists of two steps: Monte

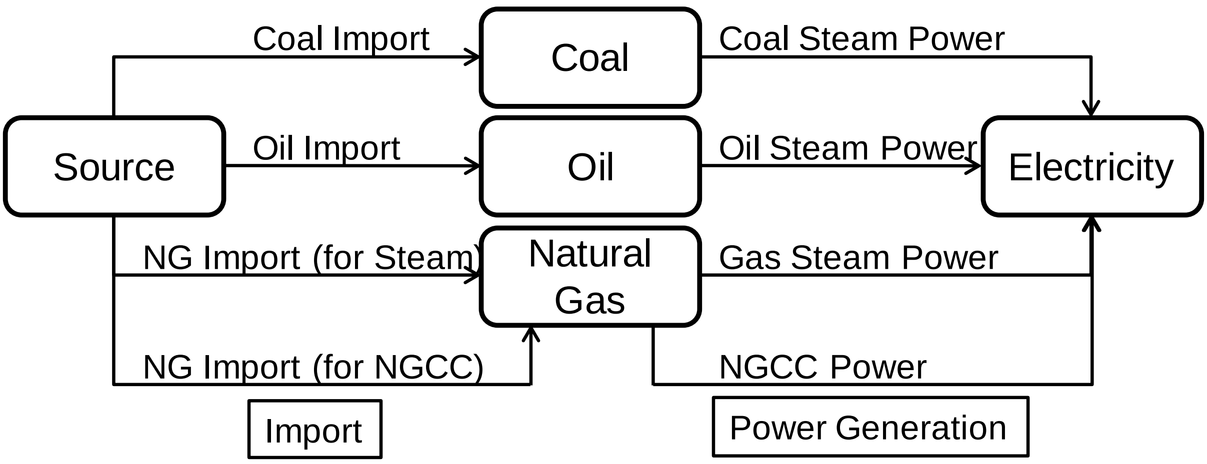


Figure 4.1 Conceptual figure of the network flow model for the electric utility sector.

Table 4.1 Meanings of parameters for the import and power generation processes.

Arc Type	c_1	c_2	α	q
Import	lower limit of import	upper limit of import	transport efficiency	import price
Power Generation	lower limit of power generation	upper limit of power generation	power generation efficiency	variable O&M cost

Carlo simulation and calculation of the risk index.

The Monte Carlo simulation consists of four steps. First, yearly change in the prices of fossil fuels and CO_2 are estimated using the GBM model as explained in the Chapter 3. Second, the minimum-cost generation mix of the electricity generation sector with certain prices of fossil fuels and CO_2 is estimated by solving the GMCF problem described in subsection 4.2.1. Third, the producer prices of each type of final energy, i.e., oil product, coal product, electricity, and town gas, are estimated by applying the Leontief price model. While theequation (3-12) is utilized for the estimation, ΔP^N is set to zero for simplification. Before estimating, input coefficients representing input from the fossil fuels to electricity generation sector are modified by the solution of the GMCF problem. Those coefficients are estimated by dividing electricity production of each type plant by fossil fuel consumption of them. Fourth, the change in energy costs the non-energy sectors is estimated. The change depends on the increases in the producer prices of energy sectors, and the energy mix of non-energy sectors. Then, denoting the share of each type of energy in the total energy consumption of a non-energy sector by X, the increase in the energy cost of the non-energy sector per unit energy consumption, $\Delta P^d = \{\Delta p_j^d\}$ can be estimated as

$$\Delta P^d = X \Delta P^e \qquad \text{where} \quad \Delta P^e = \begin{bmatrix} \Delta P^m \\ \Delta P^f \end{bmatrix}, \quad X = {}^t[X_1, \cdots, X_K], \qquad (4\text{-}5)$$

where K is the number of the types of energy.

From the Monte Carlo simulation, probabilistic density of the change in the producer prices of final energy and the energy cost for non-energy sectors are obtained. Finally, the CVaRs in those producer prices can be estimated as the index of the energy price risk.

4.3 Data and Results

4.3.1. Data and Scenarios

GMCF model requires not an increase in the price of fossil fuels and CO_2, ΔQ^E, but the level of price q_i' (1). To estimate q_i' (1), the prices of fossil fuels and CO_2 in base year are required. The average prices of them in 2005 [01] [92] are utilized as the base year prices in this study. The base year prices of coal, oil, natural gas, and CO_2 are 275 [yen/GJ], 1028 [yen/GJ], 666 [yen/GJ], and 2861 [yen/t-CO_2].

Parameters of the GMCF model are estimated from data of the generation capacity and technologies in Japan [33] [89] [90], and presented in Table 4.2. The lower limits of the quantity of imported fossil fuels and generated power are set to zero, and no upper limits are set for the quantity of imported fossil fuels. Those parameters may need to be modified for more precise simulation in the future works.

For the Leontief price model, input coefficients, G^{EE} and B^{EE}, are estimated from the material input–output table of Japan in 2005 [91], and presented in Table 4.3. The energy mix of the energy demand sectors, Y, are estimated from the energy balance table of Japan in 2005 [34], and presented in Table 4.4. This study focuses on two aggregated energy demand sectors, the industrial sector and the commercial and residential sector.

To analyze an influence of a difference in the level of the carbon price on the energy cost, this study assumes four price scenarios: ET1 scenario in which the carbon price is in a same level as the price in European Climate Exchange (ECX) [92][6], the ET2 scenario in which the carbon price increases at higher rate than ET1[7], and the ET3 scenario in which the carbon price in the base year is twice as much as that in ET2[8]. Parameters of the price are presented in Table 4.5. Note that the correlation coefficients between the fossil fuels and carbon prices are arbitrary set to zero because there is no time series data of the carbon price with enough length.

Figure 4.2 presents distribution in the prices of the three imported fossil fuels including CO_2 cost in each case. The number of iterations for the Monte Carlo simulation is set as 100,000. As the price in the base year and the rate of price change increases, peaks of the price distributions move to right, and upper tails of them become longer. The result indicates that increase in the CO_2 cost also increases the cost for fossil fuel consumers. Especially, the price of coal has the largest increase through the cases because coal has the largest CO_2 emission intensity among the fossil fuels. While the expected value and CVaR in the price of coal are apparently the smallest in the Base case, those in coal become as large as those of natural gas in the ET3 case.

4.3.2. Estimating Energy Price Risk

Figure 4.3 presents the share of each fossil fuel in the total fossil fuel demand.

---

[6] This study uses the price in ECX because the Japanese market is still in an experimental stage.
[7] The drift parameter in ET2 is set to the level when the concentration of CO_2 in the atmosphere is stabilized at 450ppm until 2100. From the IIASA GGI database [93], the CO_2 price in 2005 and 2100 are obtained, and the drift parameter is calculated from those prices.
[8] The carbon price in the base year is arbitrary set.

Table 4.2 Parameters for each arc in the network flow model.

No	Arc Name	c_1 [TJ/year]	c_2 [TJ/year]	α	q [yen/TJ]
1	Coal Import	0	∞	1	from equation (3-6)
2	Oil Import	0	∞	1	from equation (3-6)
3	NG Import (for steam)	0	∞	1	from equation (3-6)
4	NG Import (for NGCC)	0	∞	1	from equation (3-6)
5	Coal Steam Power	0	2357139	0.390	43300
6	Oil Steam Power	0	3171313	0.374	6200
7	Gas Steam Power	0	1941448	0.381	6400
8	NGCC Power	0	1731996	0.433	6000

Table 4.3 Input coefficients for the Leontief price model. The first three rows correspond to the matrix G^{EE}, and following four rows correspond to the matrix B^{EE}.

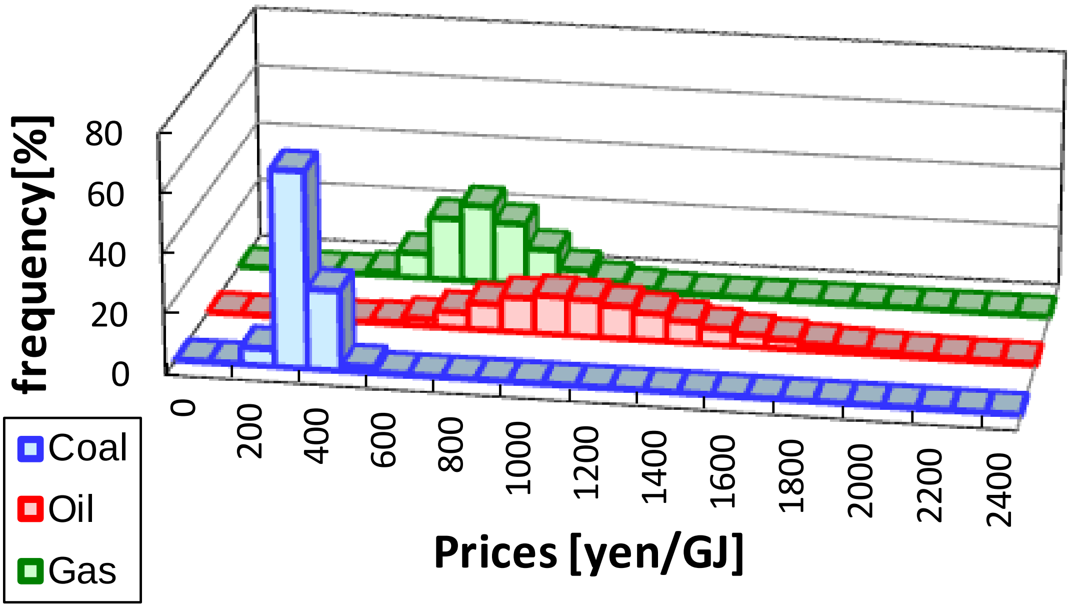
	Oil Product	Coal Product	Electricity	Town Gas
Coal	0.001	1.802	0.575	0.002
Crude Oil	1.145	0	0.091	0
Natural Gas	0	0	0.786	1.569
Oil Product	0.003	0	0.208	0.099
Coal Product	0	0	0	0
Electricity	0.005	0.003	0.061	0.014
Town Gas	0	0.001	0.002	0.021

Table 4.4 Share of each type of energies in the total energy consumption of the two energy demand sectors: the industrial sector and the residential and commercial sector.

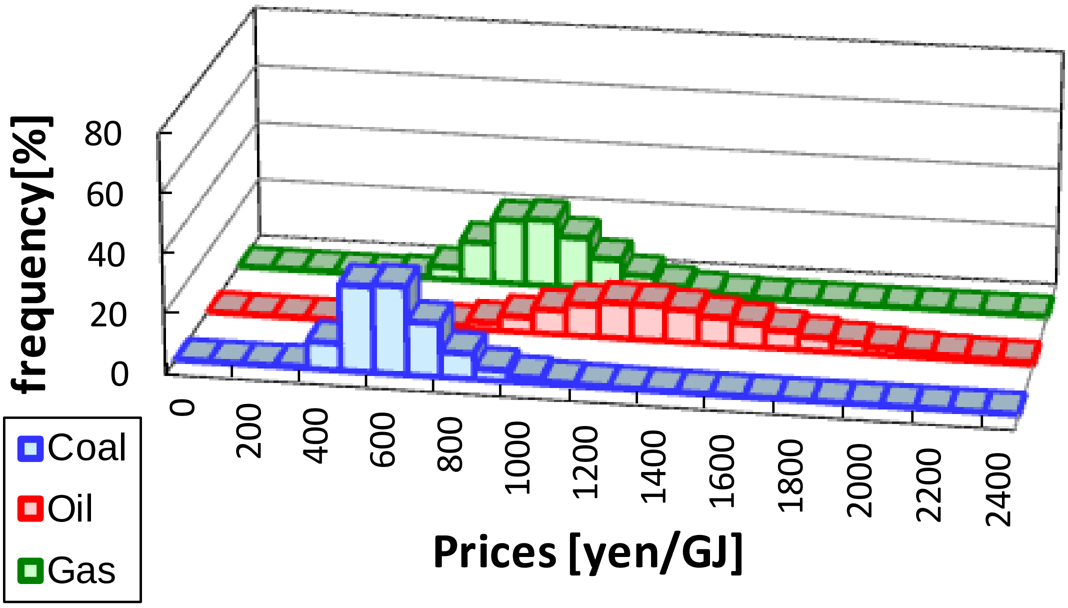
	Coal	Crude Oil	Natural Gas	Oil Product	Coal Product	Electricity	Town Gas
Industrial sector	0.087	0	0.014	0.302	0.295	0.258	0.043
Commercial and Residential sector	0.005	0	0	0.354	0.001	0.444	0.197

Table 4.5 GBM parameters and the base year prices for the carbon price in each scenario.

	drift parameter	volatility parameter	base price [yen/GJ]
Base	0	0	0
ET 1	–0.0447	0.446	2861
ET2	0.1	0.446	2861
ET3	0.1	0.446	5722

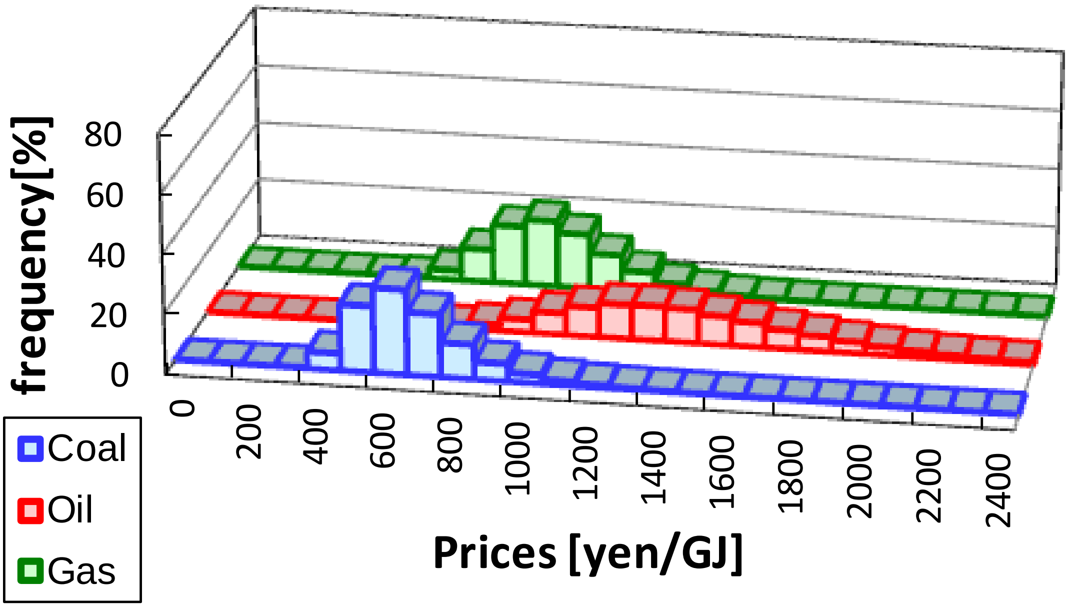


(a) Price distribution in Base case.

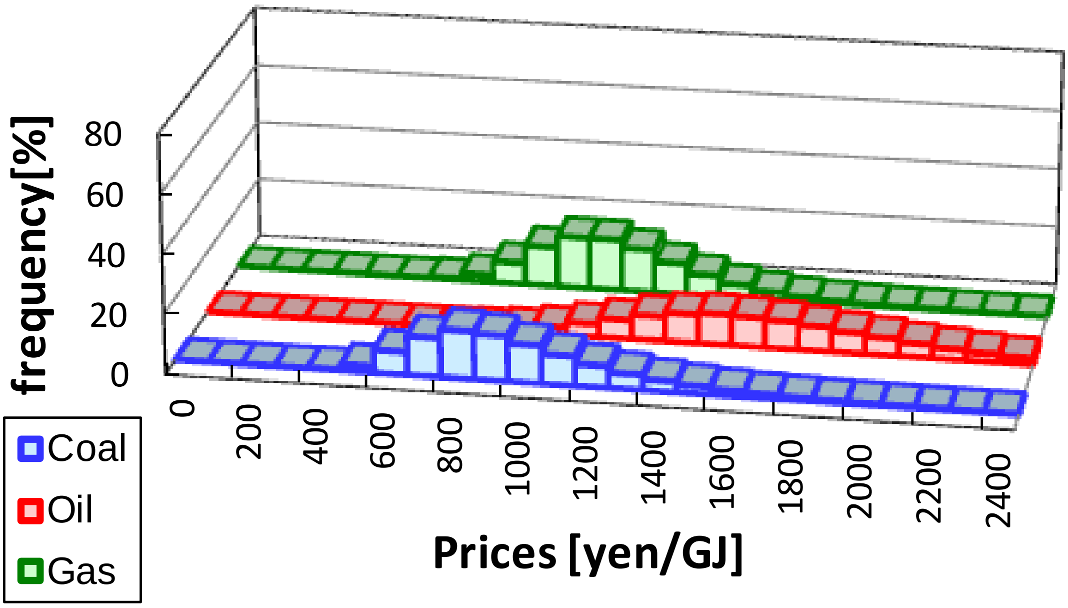


(b) Price distribution in ET1 case.

Figure 4.2 Distribution in the prices of the three imported fossil fuels including CO_2 cost in each case. The number of iterations for the Monte Carlo simulation is set as 100,000.



(c) Price distribution in ET2 case.



(d) Price distribution in ET3 case.

Figure 4.2 (continued)

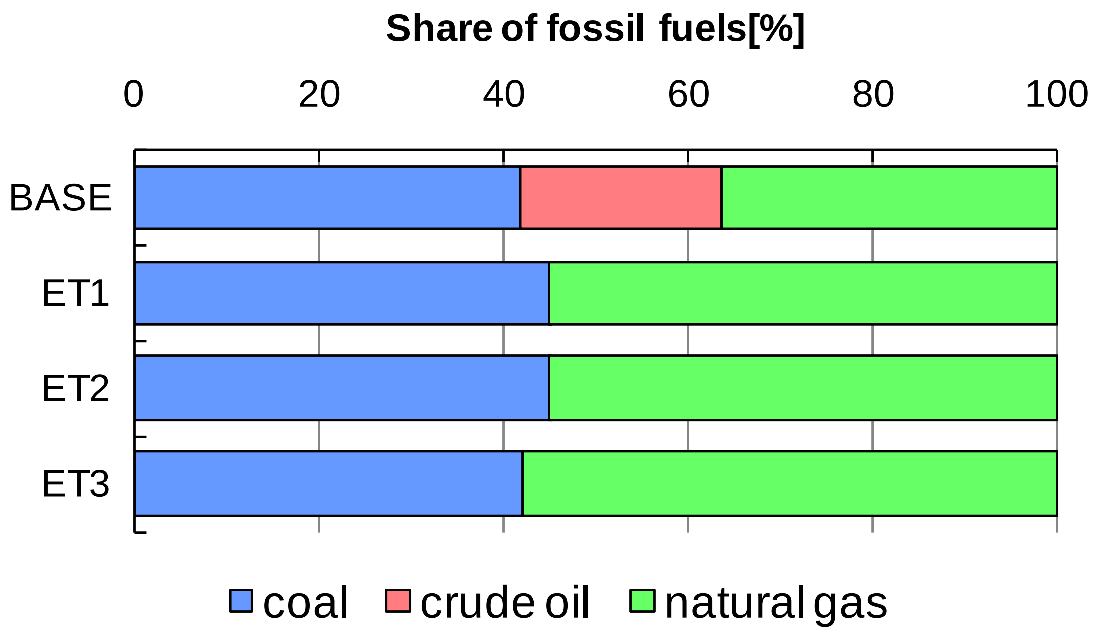


Figure 4.3 Share of each fossil fuel in the total fossil fuel demand.

The result of BASE case is the share before the generation mix is changed to minimize the generation cost, and the results of other cases are the share after the generation mix is changed. The presented result is an average of all the iterations. After the minimization, the crude oil is substituted with the coal and natural gas in the ET1 and ET2 cases. While the energy prices of coal is smaller than that of natural gas, almost all part of crude oil demand is substituted with natural gas because the capacity of coal-fired plants are limited. On the other hand, entire part of crude oil demand is substituted with natural gas in the ET3 case. In the market status of ET1 and ET2, coal is mainly chosen as the power source because the price of coal is the cheapest and the least variable. However, in the market status of ET3, natural gas is preferred to coal because the cost for natural gas is less influenced by the price of CO_2 than coal which has higher CO_2 emission intensity.

Figure 4.4 presents both the expected value and the CVaR of an increase in the producer prices of the electricity sector. Two results are presented for each case: the case before and after changing in generation mix estimated by the GMCF model (painted diamonds and non-painted squares, respectively). Before changing the generation mix, both the mean and CVaR increases as the value and volatility in the CO_2 price increases from BASE to ET3. While both indices are seldom increased from the BASE to ET1 cases, they are largely increased from the ET1 to ET2 cases, and further increased from the ET2 to ET3 cases. The result indicates that the energy price risk of the electricity generation sector will be seldom increased by the imposition of carbon costs under the present level of value and volatility in CO_2, but will be largely increased under the higher increase ratio of carbon costs purposing the stabilization in 450ppm. When the generation mix is changed, the CVaR in the ET1 case becomes smaller that in the BASE case. The result indicates that an increase in the energy price risk of the electricity generation sector by imposing the carbon cost can be compensated by changing the generation mix. On the other hand, an increase in the CVaR in the ET1 cannot be compensated by changing the generation mix.

Figure 4.5 and 4.6 presents both the expected value and the CVaR in an increase in the cost of the industrial sector and the commercial and residential (C&R) sector. The results of two cases are presented: the case before and after changing in generation mix estimated by the GMCF model (painted diamonds and non-painted squares, respectively).

Before changing the generation mix, both the mean and CVaR in the energy cost of industrial sector increase as the value and volatility in the CO_2 price increases from the BASE to ET3 cases while the CVaR in the energy cost of the C&R sector decrease from the BASE to ET1 cases. The decrease in the C&R sector is caused by

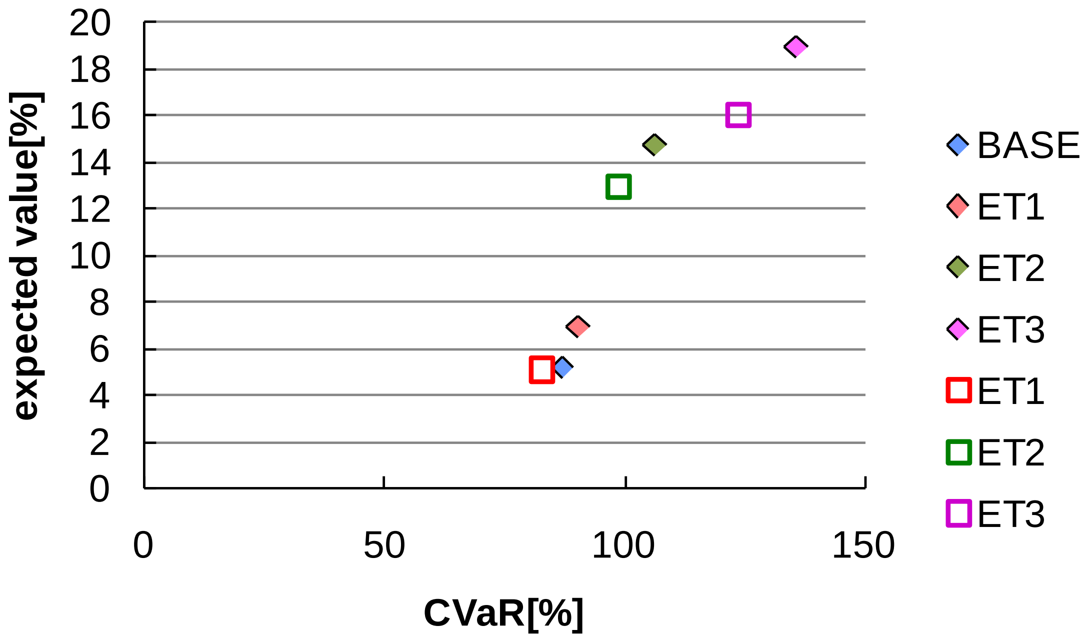


Figure 4.4 Expected value and the CVaR of an increase in the producer prices of the electricity sector.

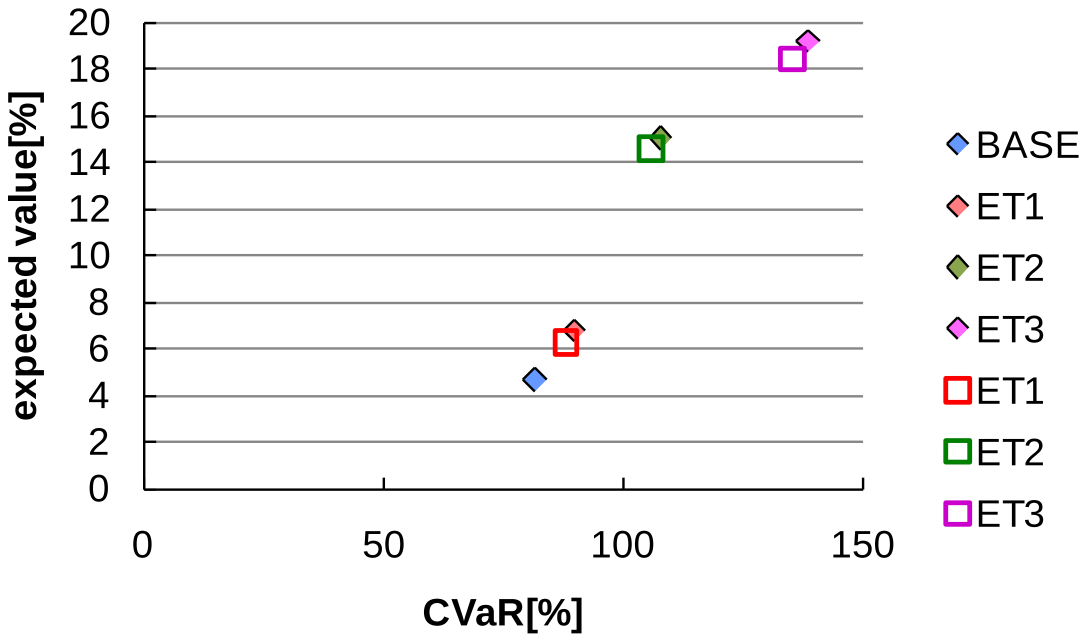


Figure 4.5 Expected value and the CVaR of an increase in the cost of the industrial sector.

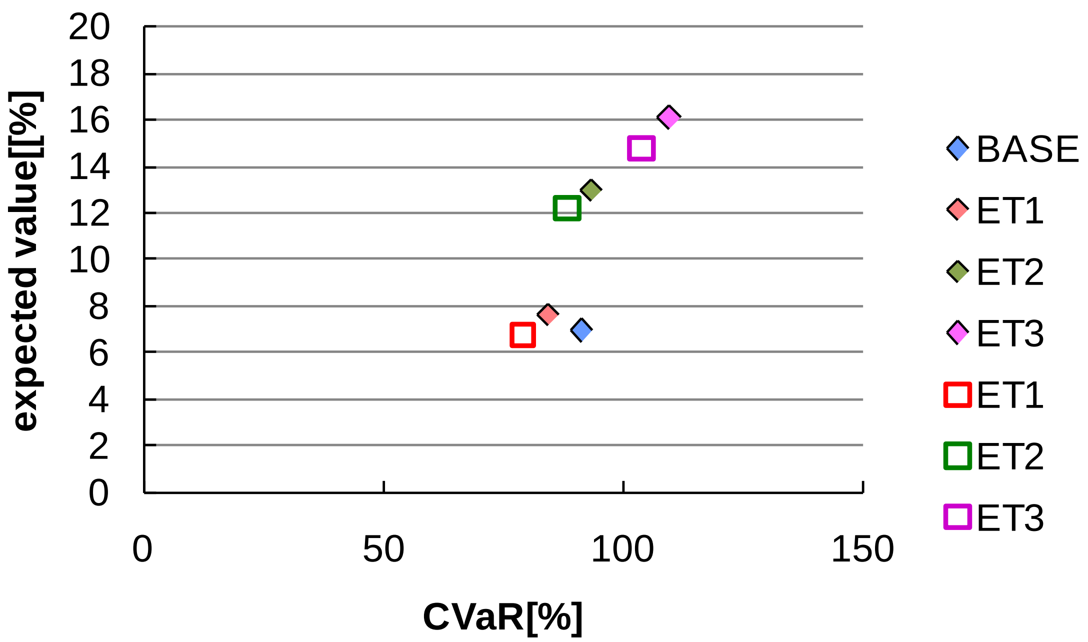


Figure 4.6 Expected value and the CVaR of an increase in the cost of the commercial and residential(C&R) sector.

the diversification of risk sources, i.e. markets affecting the energy price risk. Because this dissertation assumes that the correlation coefficient between the prices fossil fuels and CO_2 as zero, a sector consuming energy with lower CO_2 emission intensities can decrease the risk by increasing direct and indirect consumption of energies with higher CO_2 emission intensities. While the industrial sector consumes higher share of coal and coal products even before the generation mix is changed, the commerce and residential sector seldom consumes coal and coal products before the generation mix is changed. Then, only the C&R sector decreases the energy price risk from the BASE to ET1 cases. As the value and volatility in the CO_2 price increase further, i.e. in the ET2 and ET3 cases, both the mean and CVaR becomes larger than that in the BASE case.

After changing the generation mix, only the CVaR in the C&R sector can be smaller than that in before changing the generation mix in the ET1 case. For the industrial sector, the CVaR in the ET1 case cannot be smaller than that in the BASE case because the share of coal is much larger than that in the C&R sector. As the value and volatility in the CO_2 price increase further, i.e. in the ET2 and ET3 cases, the CVaR in both the sectors become larger than that in the BASE case. The result indicates that an increase in the energy price risk of the C&R sectors by imposing the carbon cost can be compensated by changing the generation mix. On the other hand, an increase in the CVaR in the ET1 cannot be compensated by changing the generation mix. In the ET2 and ET3 cases, the change in the generation mix cannot compensate an increase in the risk in both the sectors.

Figure 4.7 presents the ratio between the mean and six-folded sigma in producer prices of the electricity sector and the energy cost of the industrial and C&R sector estimated from 500 sets of Monte Carlo simulations with 100,000 iterations, respectively. The result of Monte Carlo simulation has smaller deviation from the mean than this ratio by the probability of 99.7%, i.e. $\pm 3\sigma$. In the BASE case, the ratio of each sector is around 3% which is the similar value as that of fossil fuel prices. In the ET1 case, the ratio is around 3.4% which is the similar value as that of CO_2 prices. In the ET3 and ET4 case, the ratio becomes the same level as the BASE case. In those cases, the ratio becomes smaller because drift parameters are larger than ET1 case. As the drift parameter becomes larger, the larger part of an increase in the price of CO_2 becomes deterministic. C&R sector has smaller ratio than other sectors because they consume smaller quantity of coal which has higher CO_2 emission intensity than other fossil fuels.

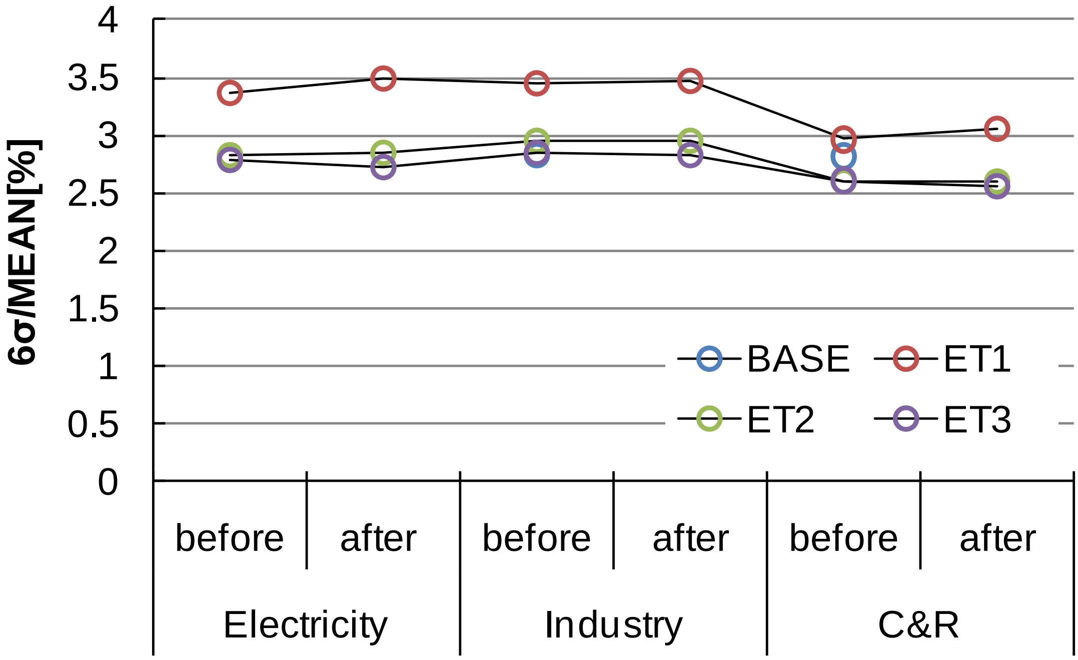


Figure 4.7 Ratio between the mean and six-folded sigma of the CVaR of the producer prices of electricity sector and energy cost for the C&R sectors. The result of Monte Carlo simulation has smaller deviation from the mean than this ratio by the probability of 99.7%, i.e. ±3σ.

4.4. Discussions

The analysis in this chapter quantified a risk of an increase in the producer prices of the electricity generation sector and energy cost of the industry and C&R sectors caused by an increase in the prices of fossil fuels and CO_2. The generation mix of the electricity generation sector can be changed to decrease the risk under the restrictions of existing generation capacity.

The results indicate that the energy cost of the industrial sector is more affected by that of the C&R sector because the share of coal in the industrial sector is larger than that in the C&R sector. The results indicate the energy mix of non-energy sectors need to be endogenized into the analytical framework when we quantify the energy price risk of those sectors.

The energy price risk of the electricity generation and C&R sectors can be compensated by changing the generation mix if the levels of value and volatility in the CO_2 market are equal to those in the ECX market. On the other hand, the energy price risk of the industrial sector cannot be compensated even if those levels are equal to those in the ECX market because the sector consumes more coal and coal products than the electricity generation and C&R sectors. If the levels of value and volatility in the CO_2 market become higher than the present status, the change in the generation mix cannot compensate an increase in the risk caused by the CO_2 market. In order to decrease the risk further in those cases, the long-term portfolio selection such as change in the generating facility mix is also required.

Although I did not make upper and lower constraint on the share of each types of generation plant, the electricity generation sector cannot decrease the share of crude oil fired plant to zero because of the peak load. Because the demand for electricity changes by time and by season, the electricity companies need to turn on and off fossil fuel fired plants to match the demand and supply of electricity. Since such an operation of plants makes removing the crude oil fired plants impossible, this study overestimates the risk reduction effect of changing generation portfolio. This problem of operation needs to be endogenized to the model in the future works.

In the next two chapters, the cost of CO_2 emission and the influence of changing the generation portfolio are not included in the analytical framework because I would like to concentrate on analyzing the time series change in the risk caused by the prices of energy, and to clarify the main causes of the risk.

Chapter 5

Energy Price Risk of Non-Energy Industries

5.1. Motivation and Data

In this chapter, the energy price risk of Japanese non-energy sectors is estimated during the period 1970–2000 by applying the I−O portfolio analysis. 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 energy price risk, the energy cost per unit production, and the rate of added value are analyzed. Some implications are derived from the results of these analyses.

Input coefficients A and M in the Leontief price model are calculated from the time series input–output tables (TSIO) [94] for the period 1970−2000. Although the tables have 155 standardized sectors, we reclassified them into 37 sectors for simplicity. Table 5.1 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 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.

Table 5.1 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		

5.2. Results

5.2.1. Fossil Fuel Price Elasticity in Energy Conversion Sectors

Figure 5.1 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. Those input factors are further decomposed into direct and indirect factors.

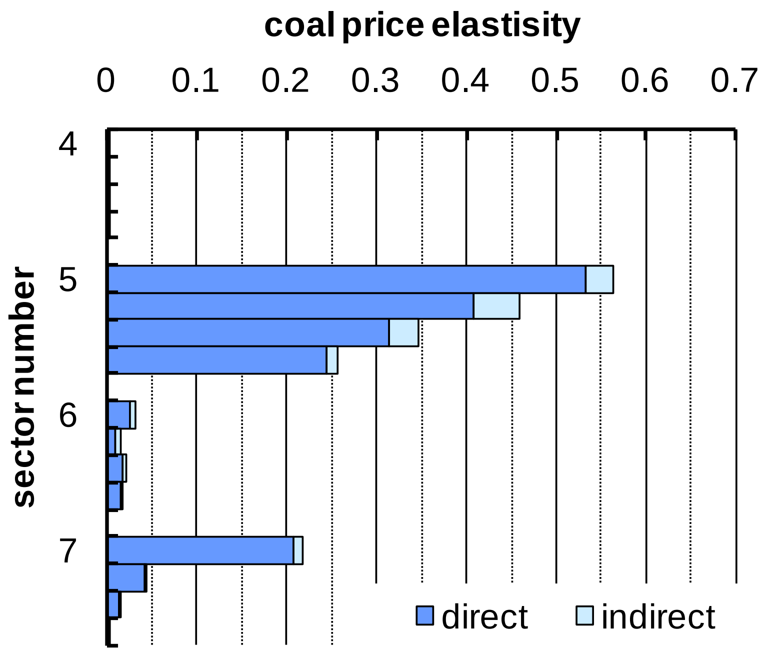
In the oil products sector (No. 4), direct input factor of imported crude oil increased in the 1970s and decreased in the 1980s. Through the analysis period, the elasticity is slightly increased. In the 1970s, the availability factor of oil refinery decreased from 90.7% (1970) to 66.0% (1980) in this period [95]. The decrease is caused by decreased demands for oil products through the recession and improvement of energy usage after two oil shocks. On the other hand, in the 1980s, the availability factor of refinery increased from 66.0% (1970) to 77.3% (1990), and 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 [94]. However, the decrease in the 1980s could not compensate for the increase in the 1970s because there are few developments in the 1990s.

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 [82]. Actually, the energy efficiency in coal production process increased from 80.6% to 93.9 % during the analysis period [95].

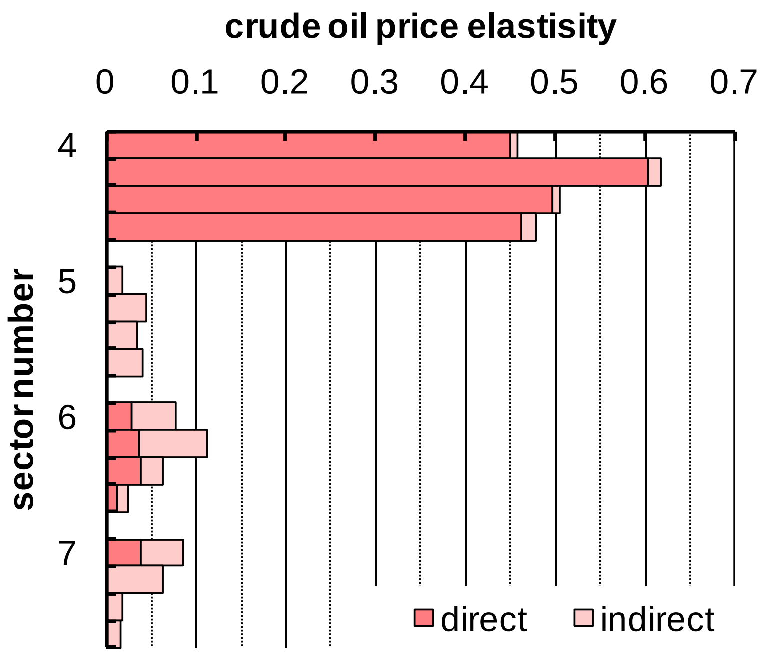
In the electricity sector (No. 6), both the direct and indirect input factors of imported crude oil decreased through the analysis period. In this sector, the direct and indirect factors correspond to the consumption of crude oil and heavy oil, respectively. Japan had replaced oil-fired power plants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

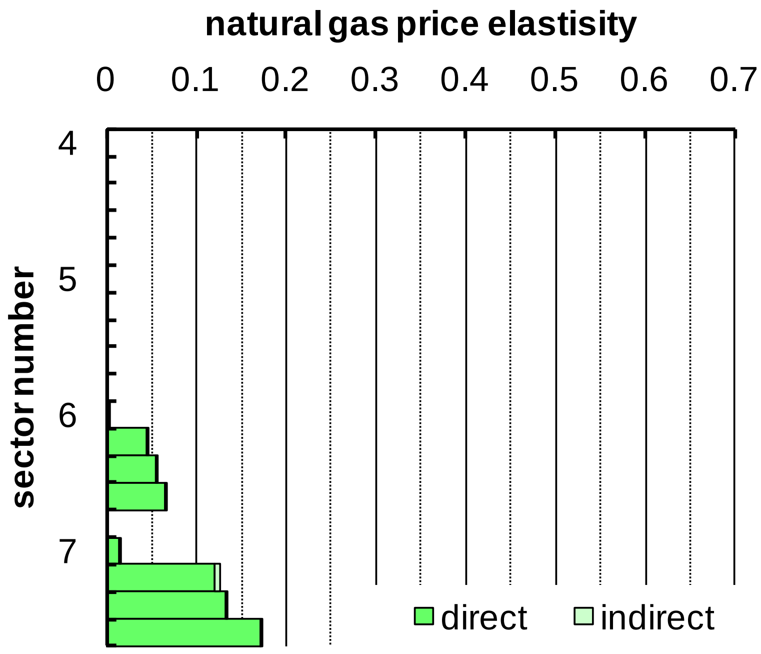


(a) coal price elasticity

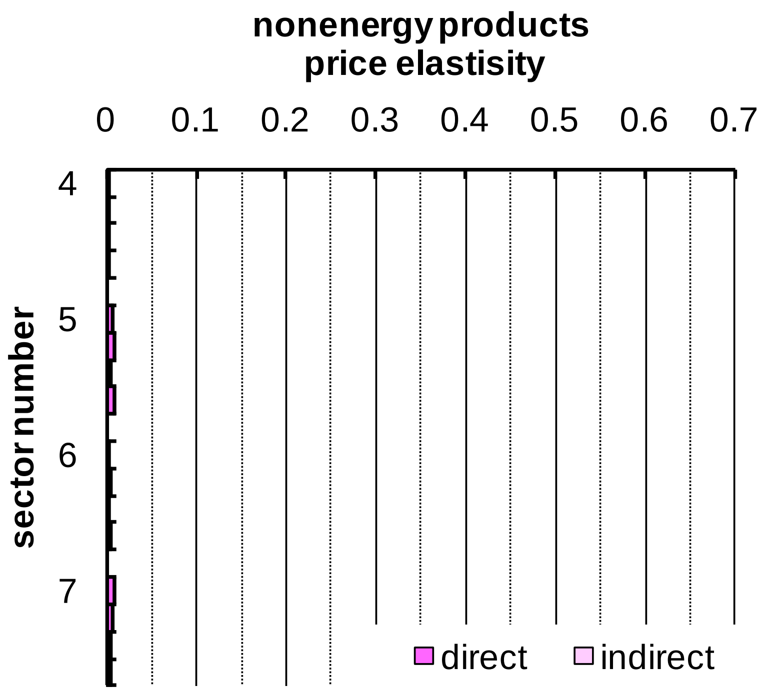


(b) crude oil price elasticity

Figure 5.1 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.



(c) natural gas price elasticity



(d) non-energy products price elasticity

Figure 5.1 (continued)

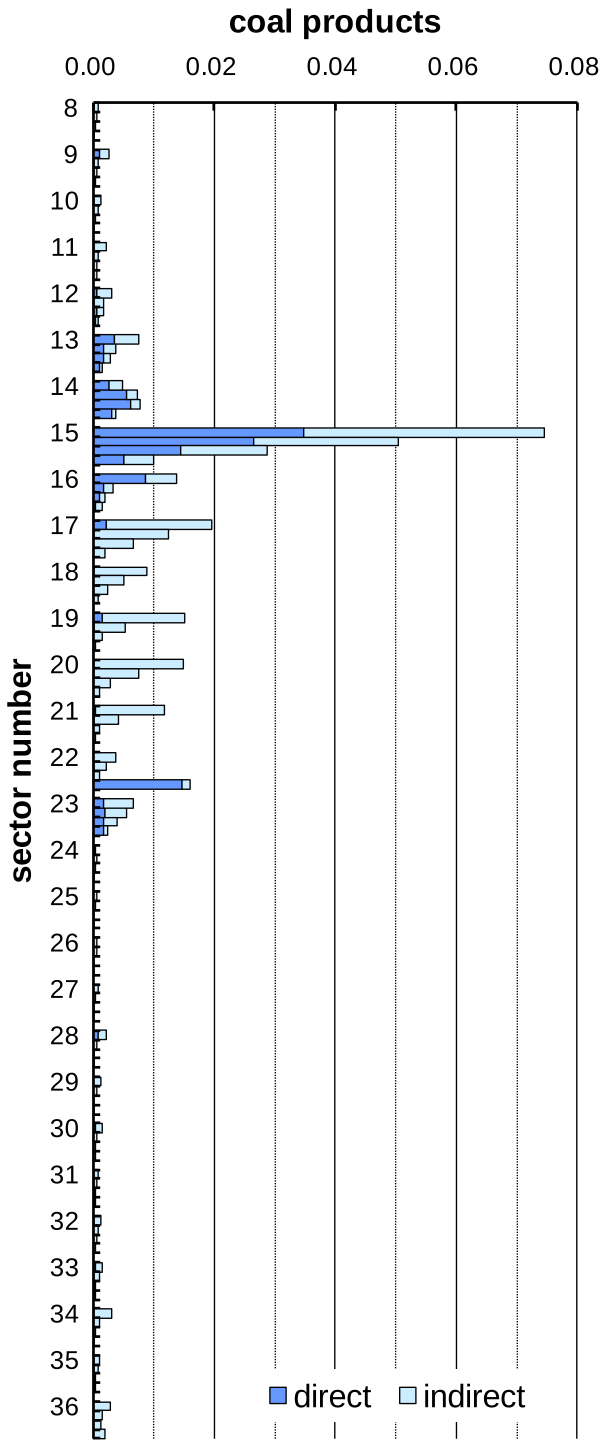
were much smaller than those of fossil fuels; hence, they can be ignored.

5.2.2. Fossil Fuel Price Elasticity in Non-Energy Sectors

Figure 5.2 presents the fossil fuel price elasticity in the producer prices of 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 5.2, the input factors of fossil fuels, i.e. coal, crude oil, and natural gas, are totaled with that of coal products, oil products, and town gas, respectively, because the input factors of fossil fuels are relatively small in comparison with those of final 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. Those input factors are further decomposed into direct and indirect factors.

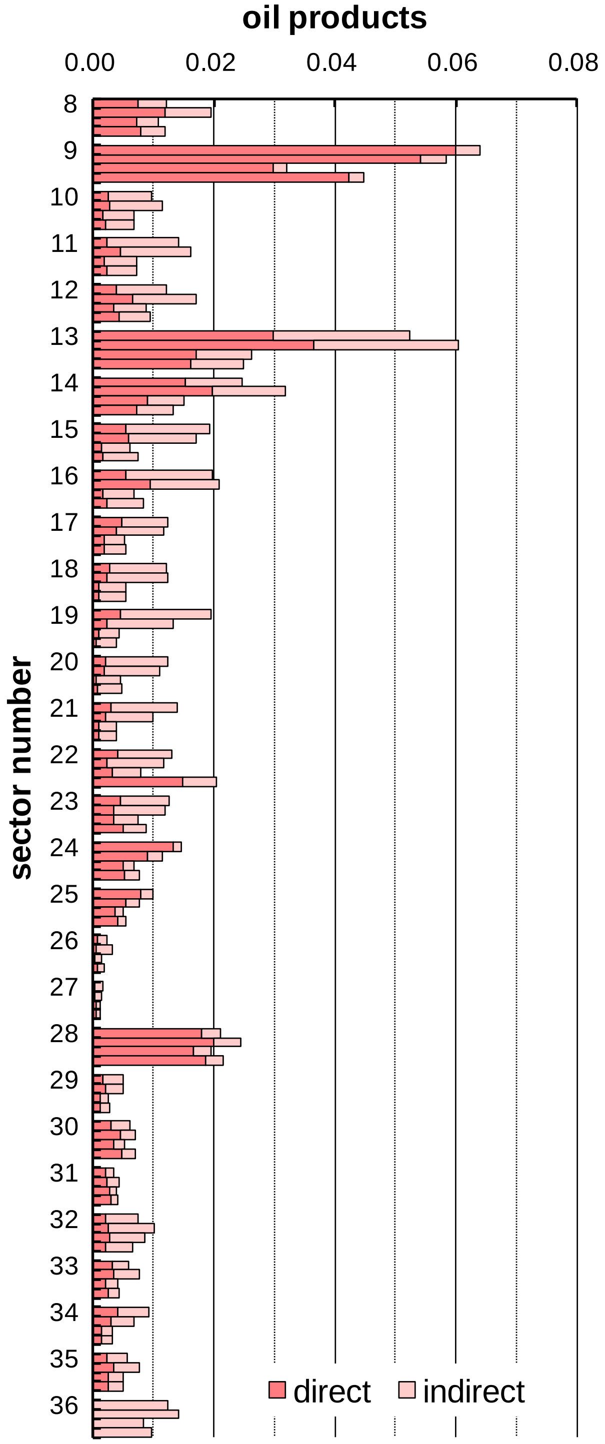
In the agriculture, forestry, and fishing (No. 8), mining (No. 9), chemical products (No. 13), cement (No. 14), and transport (No. 28) sectors, the direct input factors of oil products were relatively large. The main usages of oil products in those sectors are heating for greenhouses in the agriculture sector, machine engines in the mining sector, feedstock in the chemical product sector, heating for the firing process in the cement sector, and fuels in the transport sector. In those sectors, input factors of 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 those sectors are regarded as indirect inputs. The internal flow indicates input from an upstream process to a downstream process; for example, an 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 1980s due to the development of production process. For example, the index of availability factor in the chemical products sector is increased by 18% during the1980s [96]. The cement sector also replaced heavy oil with coal and electricity; the share of coal products, oil products, and electricity are changed from 5.4%, 85.0%, and 9.1% to, 52.6%, 28.7%, and 16.5%, respectively [97]. On the other hand, the agriculture, forestry, and fishing sector and transport sector did not decrease the input factor of oil products, and the mining sector rather increased this factor in the 1990s. For the agriculture, forestry, and fishing sector, heat sources such as for greenhouses did not be replaced by other types of energy than oil products. Similarly, the transport sector seldom changed its fuel mix from oil products to other types of energy. For the mining sector, the industrial scale of the sector has



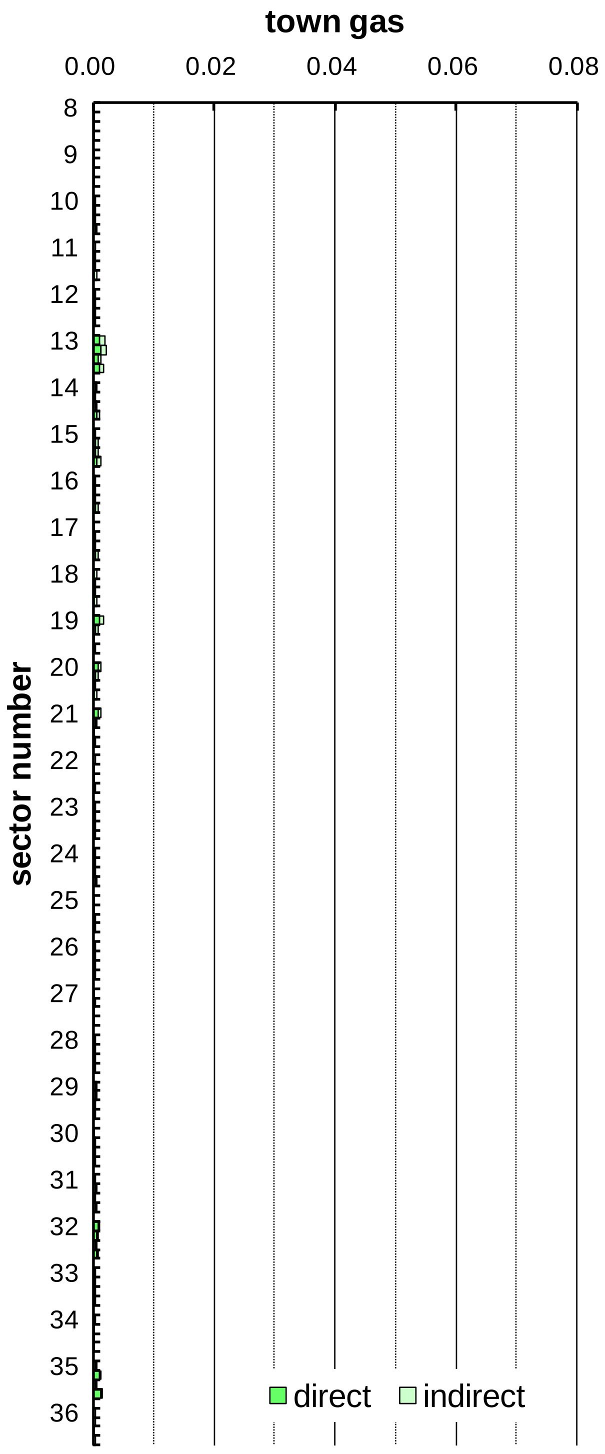
(a) elasticity of coal products plus imported coal

Figure 5.2 Fossil fuel price elasticity in the producer price of non-energy sectors. (a), (b), (c), and (d) present the elasticities of coal products plus imported coal, oil products plus imported crude oil, town gas plus imported natural gas, and electricity, respectively.



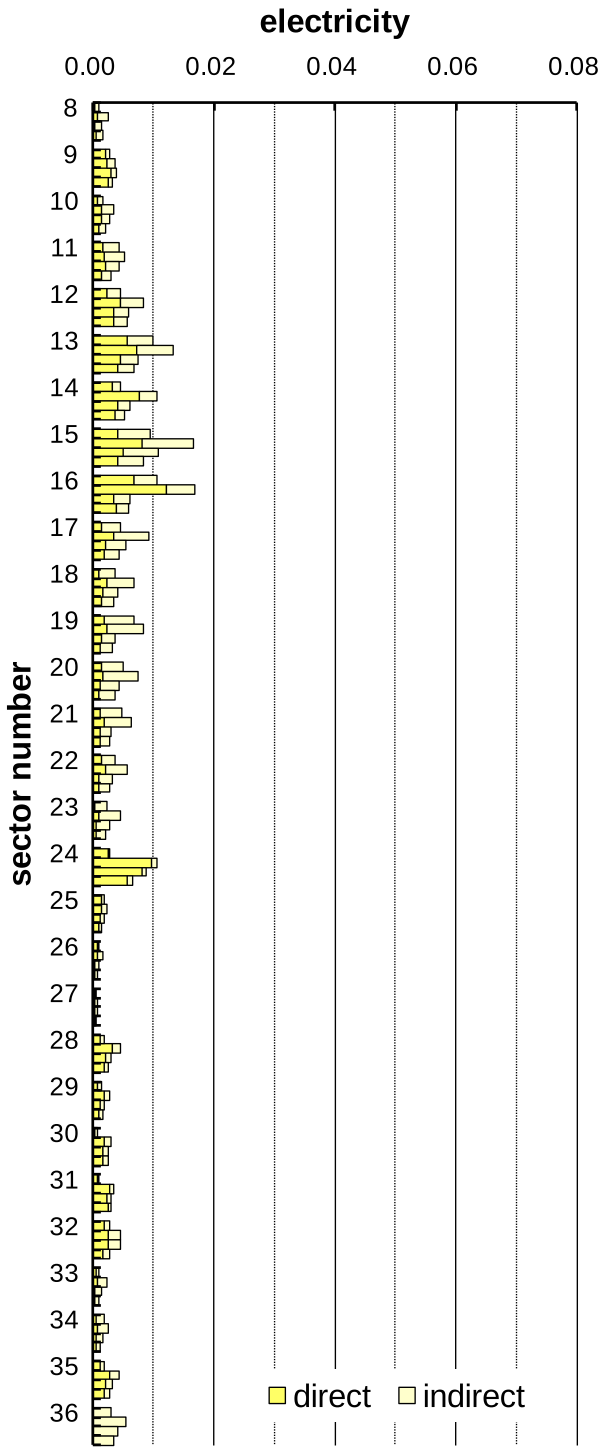
(b) elasticity of oil products plus imported crude oil

(Figure 5.2. continued)



(c) elasticity of town gas plus imported natural gas

(Figure 5.2 continued)



(c) elasticity of electricity

(Figure 5.2 continued)

been decreased during the 1990s; the production value of the sector decreased by 40% during the period [93]. However, this change seldom influenced other sectors because the mining sector's production was very small, occupying less than 0.2% of the total production in Japan though the 1990s [93].

The steel sector (No. 15) has the largest direct and indirect input factors of coal products during the analysis period. The direct factor is 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 [87].

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 as explained before. In the water services and waste disposal sector, the input factor of oil products decreased and that of electricity increased. In the water services and waste disposal sector, the energy saving and recovery technologies such as lowering the temperature in sludge-drying process and recycling the sludge as heat source has decreased the consumption of oil products. In the commerce sector, the oil products for heat source are substituted with town gas and electricity during the analysis period. The share of oil product in total energy demand decreased from 68.1% to 29.8% from

1970 to 2000 [01].

The input factors of electricity in many sectors have showed a trend similar to that of crude oil in the electricity sector, i.e. increasing in the 1970s and decreasing in the 1980s and 1990s, indicating that oil substitution in the electricity sector indirectly decreased the input factors of 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 decreased, the input factors of oil products decreased in the 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. 22) sector was possibly caused by the change in statistical classification explained in 5.2.1.

5.2.3. Energy Price Risk of Non-Energy Sectors

The CVaR, an index in the energy price risk of non-energy sectors, can be estimated from the fossil fuel price elasticity and the probabilistic density of an increase in the prices of fossil fuels. Further, the CVaR in the non-energy sectors are decomposed into the input factors of each type of energy. Figure 5.3 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 the Figure 5.3, the input factors of coal, crude oil, and natural gas are totaled with those of coal products, oil products, and city gas, respectively. Figure 5.4 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, respectively. Figure 5.5 presents the ratio between the mean and six-folded sigma in the producer prices of non-energy sectors estimated from 500 sets of Monte Carlo simulations with 100,000 iterations. The result of Monte Carlo simulation has smaller deviation from the mean than this ratio by the probability of 99.7%, i.e. ±3σ. The ratios are nearly 3% in the prices of all the sectors because the ratios in the prices of fossil fuels are nearly 3% as presented in section 3.4. This

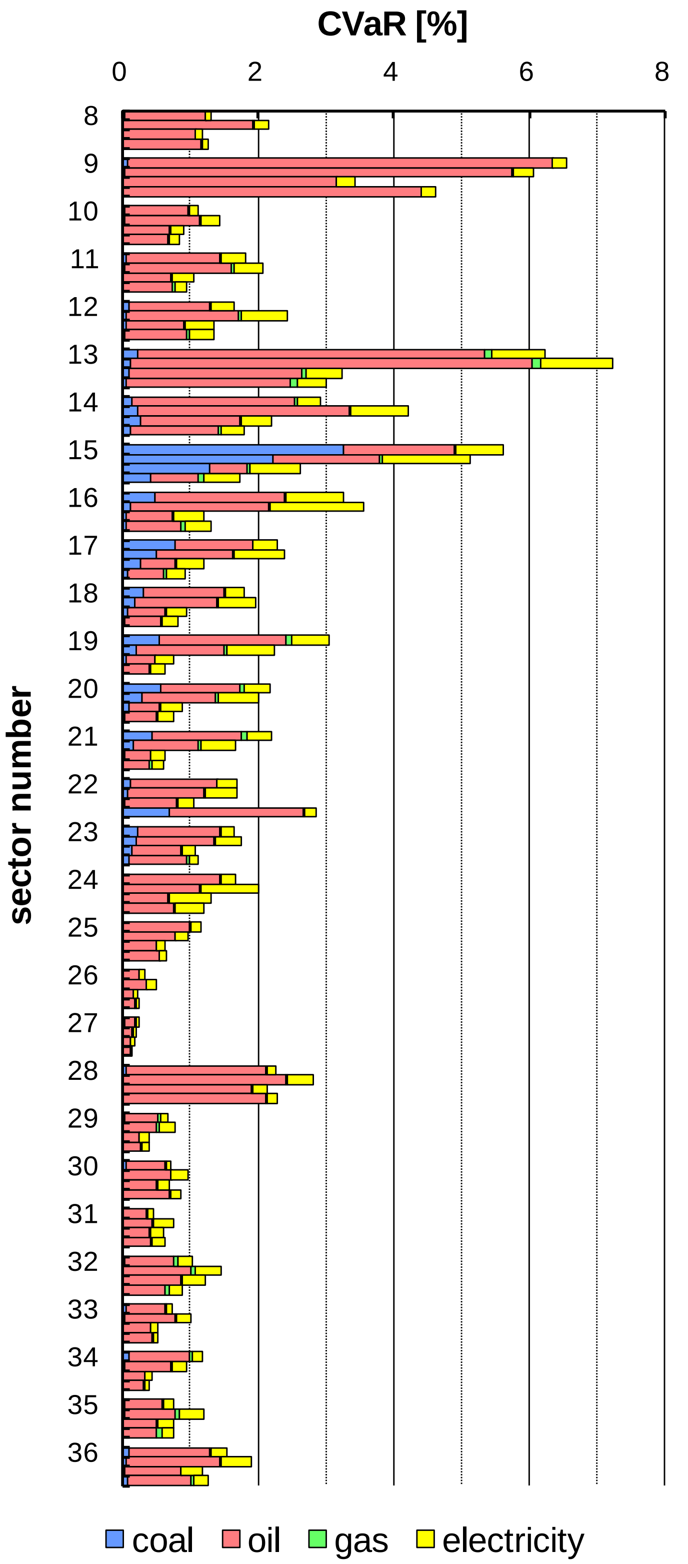


Figure 5.3 CVaR in the producer prices of each non-energy sector.

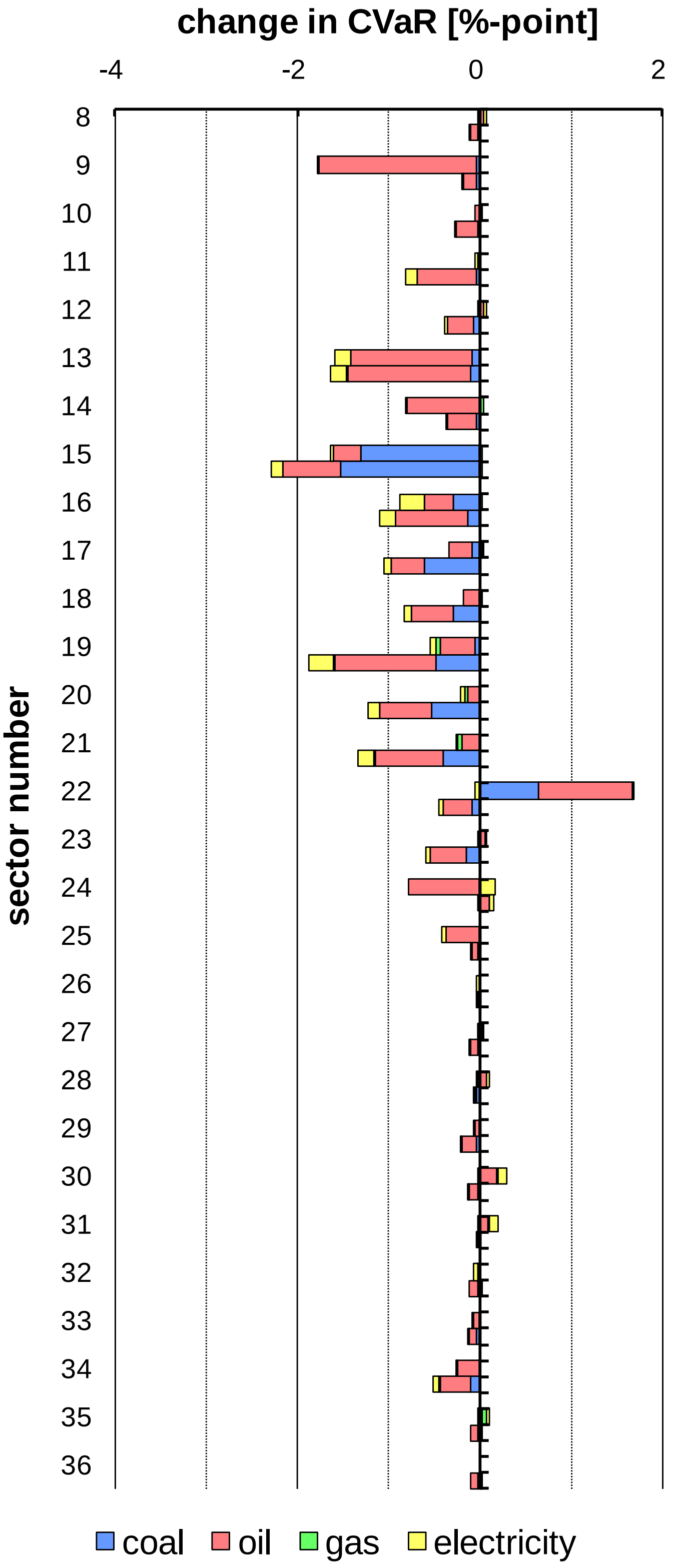


Figure 5.4 Change in the CVaR during1970–2000. The first bar represents the change in direct input factors, and the second bar represents the change in indirect input factors.

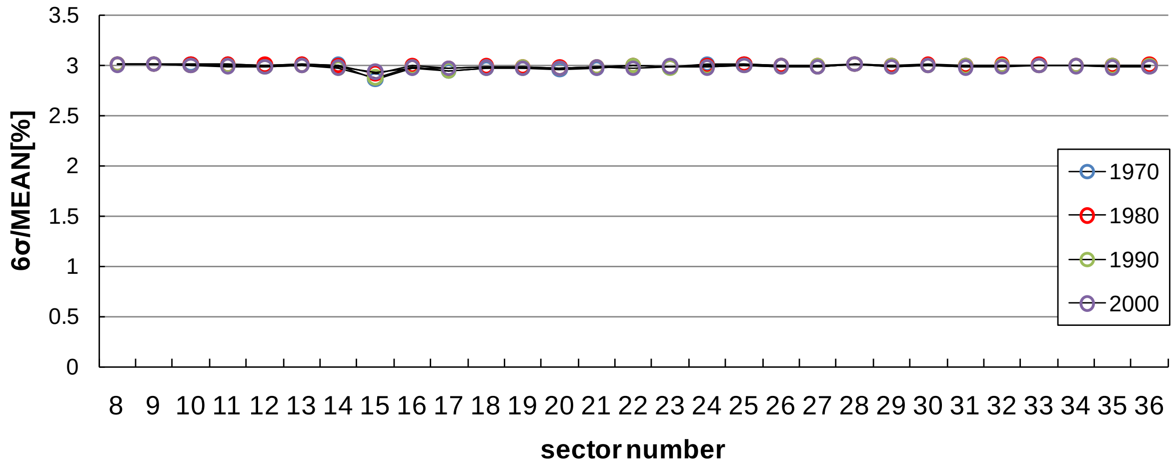


Figure 5.5 Ratio between the mean and six-folded sigma of the CVaR in the producer prices of non-energy sectors. The result of Monte Carlo simulation has smaller deviation from the mean than this ratio by the probability of 99.7%, i.e. ±3σ.

accuracy is enough to clarify the trend of the change in CVaRs and its decomposition because relative relation among the value of CVaRs in the sectors is seldom changed by this size of errors, especially in the sectors with large CVaR value.

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 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) 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 CVaR was decreased during the analysis period, the agriculture, forestry, and fishing (No. 8) and transport (No. 28) sectors were the exceptions; the CVaR in those sectors did not decrease through the analysis period.

As a result, the CVaR in those 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.

Those results indicate that the decrease in a CVaR and its breakdown depend on whether the sector locates in the upstream or downstream of the production chains in the domestic industry. 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.

5.2.4. Relationship among Energy Cost, Profit, and Risk

Next, 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 [94].

Figure 5.6 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

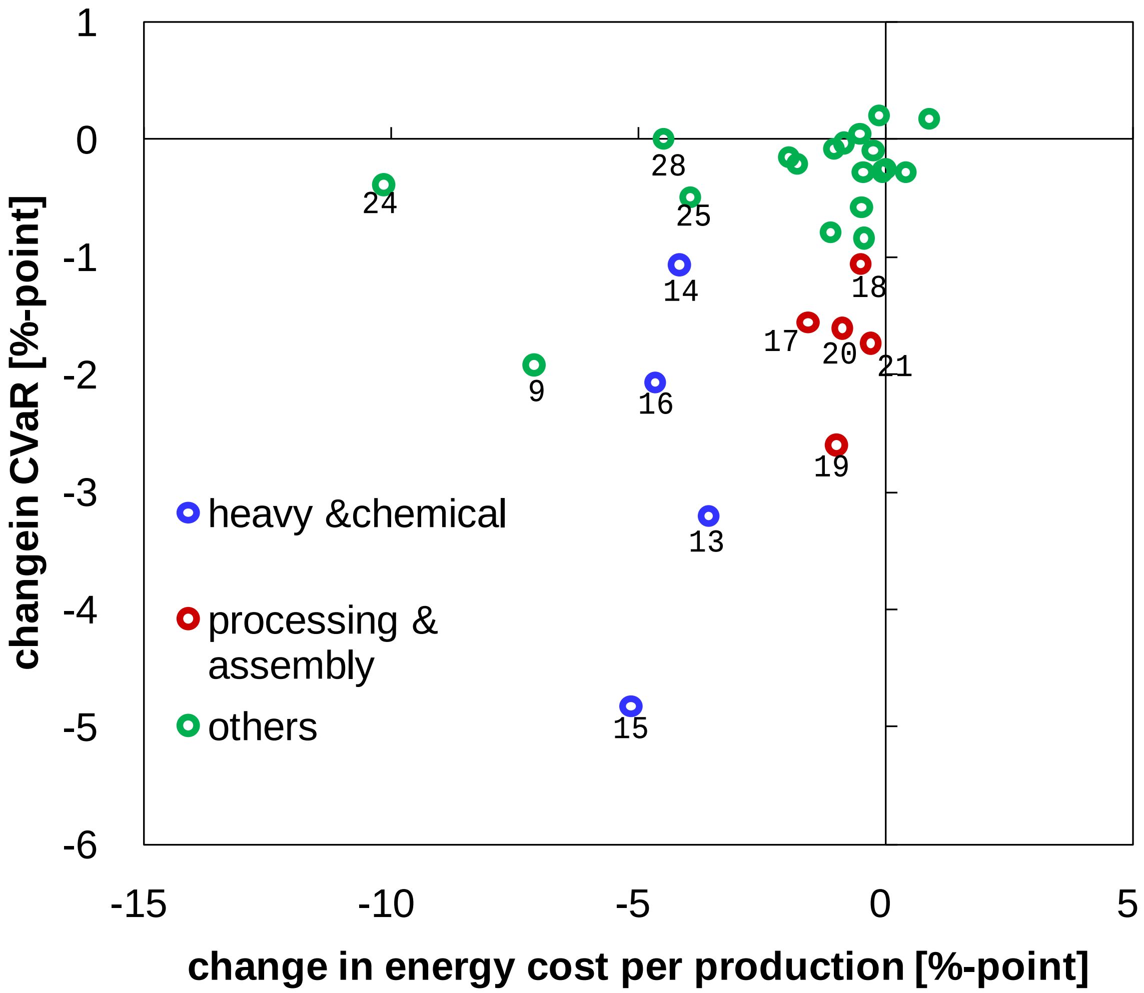


Figure 5.6 Relationship between the change in the energy cost per production and CVaR during the analysis period.

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 nonferrous 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 decreased 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 nonferrous 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 5.7 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. However, the increase in the added value varied among the manufacturing sectors with a similar

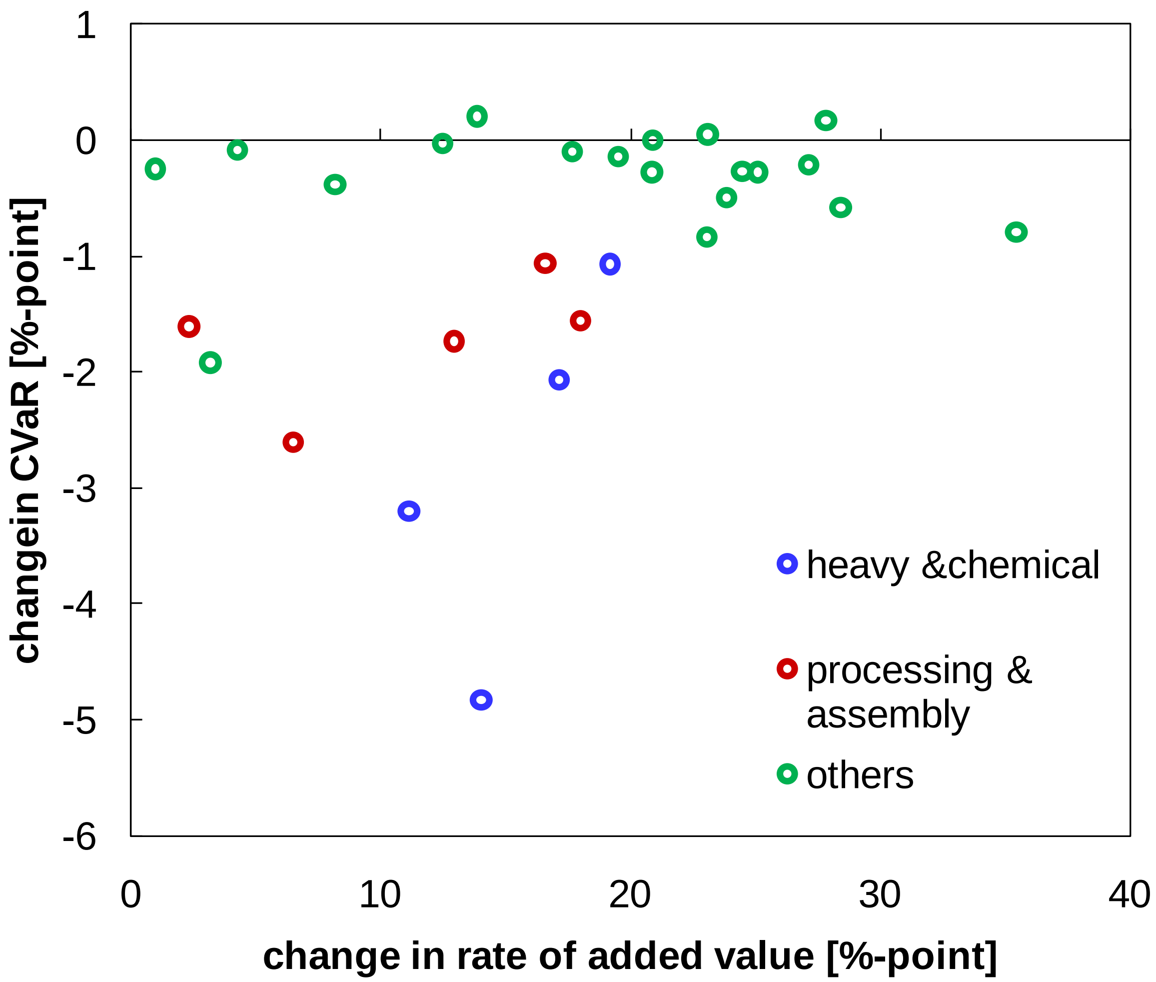


Figure 5.7 Relationship between the change in the rate of added value and the CVaR through the analysis period.

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.

5.3. Discussions

In this chapter, the I–O portfolio analysis is applied to quantify the energy price risk of the non-energy sectors in Japan during the period 1970–2000, and the cause of a reduction in risk is clarified by decomposing the risk index of each sector. The results indicate that almost all sectors decreased their CVaR through the analysis period. The reduction of the risk in the non-energy sectors were depended on the improvement in energy usage in a portion of sectors, such as the coal products, chemical products, and steel sector. To decrease the risk further, such improvements are also required in other sectors.

Measures in the oil products sector are the most important to decrease the risk because this sector is located upstream of all the non-energy sectors in the hierarchical structure of industry. The growth of added value is the 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 greenhouses, 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 nonfossil 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, policy makers 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 needs 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.

Chapter 6

Energy Price Risk of Household Sector

6.1. Motivation

In addition to the energy price risk of Industrial, transport, and commerce sectors analyzed in the previous chapter, the energy price risk of the household sector needs to be analyzed because energy consumption by the sector is increasing as presented in Figure 1.1. Lifestyle changes, an increase in the number of household appliances, and a decrease in the number of people per family are main causes of an increase in the energy consumption of the household sector in Japan. Figure 6.1 presents the number of household appliances per 100 families. The number of air-conditioners and televisions per family continues to increase, and new types of appliances, such as personal computers and toilets with hot water, have been widely deployed. On the other hand, the size of families has continued to decrease. While the population of Japan increased from 103.7 to 127.8 million during the period 1970–2007, the average family size decreased from 3.98 to 3.14 during the same period [01], due to a trend toward nuclear family and delayed marriage. These lifestyle changes have increased the direct consumption of energy in the household sector, and appear to increase the energy price risk.

In this chapter, the energy price risk of Japanese household sector is estimated during the period 1995–2005 by applying the I–O portfolio analysis. While the analysis in the previous chapter used conventional monetary based I–O tables, we develop hybrid-unit I–O tables [40], which represent energy inputs in energy units and non-energy products in monetary units. Import prices of six energy products, coal, crude oil, natural gas, naphtha, LPG, and heavy oil, are input to the model as probabilistic variables, i.e., as the cause of energy price risk. Some policy implications are derived from the results.

6.2. Methodological Developments

6.2.1. Increase in Household Expenditure and its Decomposition

An increase in the total expenditure of the household sector, caused by an

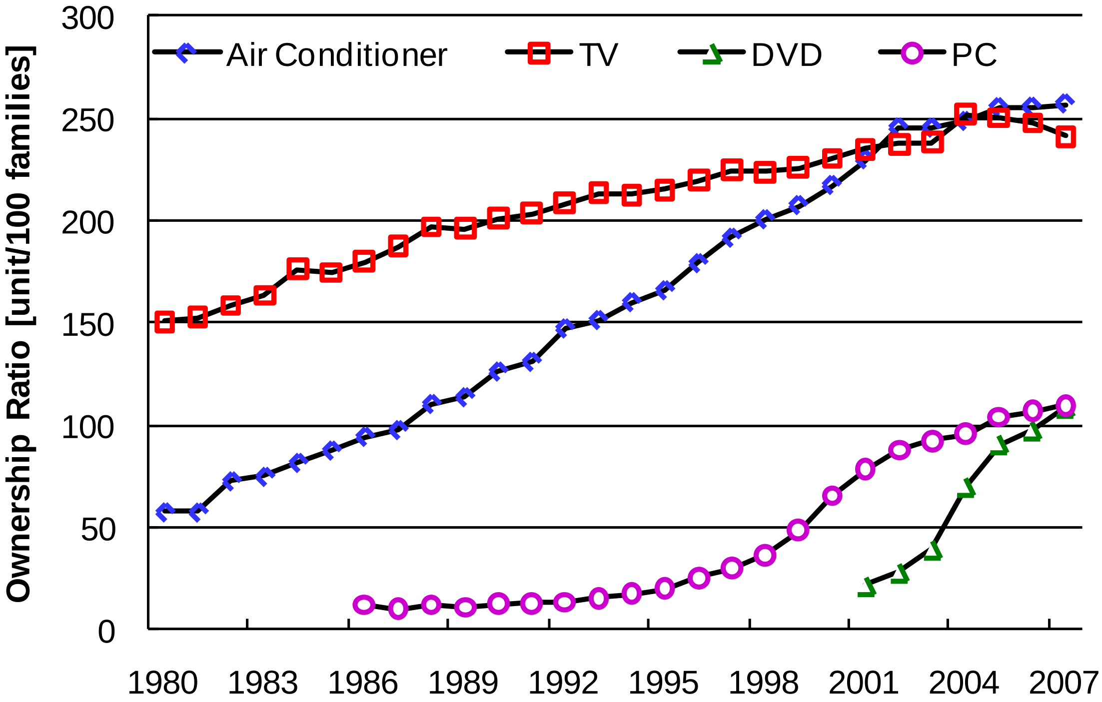


Figure 6.1 Number of household appliances per 100 families.

increase in the price of energy, depends on both an increase in the price of the domestic sectors, ΔP^E and ΔP^N, and the share of each sector in household expenditures. Then, an increase in household expenditure ΔP^H can be obtained as the weighted average of increases in the producer prices in each sector

$$\Delta P^H = W(I - B^t)^{-1} G^t \Delta Q = W \Delta P \,. \tag{6-1}$$

A vector representing the share of each sector in household expenditures, W, is used as the weight. By diagonalizing W in the equation (6-1), the input factors of each domestic sector appear as elements of a vector in the left side of the equation.

The CVaR for ΔP^H over the confidence level β is estimated as

$$CVaR^H = (1-\beta)\int_{\Delta P^H \geq \alpha_\beta^H} \Delta P^H \pi(\Delta Q^E) d\Delta Q^E \,. \tag{6-2}$$

where α_β^H denote the threshold value of ΔP^H, defined as the maximum values of ΔP^H under the confidence level β.

6.2.2. Hybrid-unit I–O tables

While a conventional monetary based I–O table is utilized in the previous chapter, a hybrid-unit I–O table in which transactions of energy and non-energy products are represented by quantities and monetary values, respectively, is utilized in this chapter. The hybrid-unit I–O tables allow accurate modeling of the energy balance among the sectors [40]. There are four types of input coefficients in matrices B and G: an input among the energy sectors, an input from the energy to non-energy sectors, an input from the non-energy to energy sectors, and an input among the non-energy sectors. The units of those coefficients are [MJ/MJ], [MJ/yen], [yen/MJ], and [yen/yen], respectively. As a result, the vectors of the prices and weight also include two types of elements. The unit of the elements in the price vectors, Q and P, is [yen/MJ] for energy sectors and [yen/yen] for non-energy sectors; the unit of the elements in the weight vector, W, is [MJ/yen] for energy sectors and [yen/yen] for non-energy sectors.

6.3. Data and Results

6.3.1. Hybrid-unit I–O Table of Japan

Coefficients *A*, *M*, and *W* in the equation (3-4) and (6-2) Leontief price model are calculated from the hybrid-unit I–O table. To create the hybrid-unit I–O table, we need both monetary and quantity base data. The 1995–2000–2005 linked I–O tables [98] are adopted as the monetary base data, and the quantity I−O tables [99], energy balance tables [97], and the EDMC Handbook of Energy and Economic database [01] are adopted as the quantity base data. The industrial sectors are reclassified into 48 sectors: 16 energy sectors and 32 non-energy sectors. Inputs from the energy and non-energy sectors are presented by energy and monetary units, respectively. Table 6.1 lists the names and numbers of each sector. The renewable energy sector is defined as an external sector receiving no input from other domestic sectors. The cost of gathering renewable energy is included in the investments by energy conversion sectors such as the electricity generation and heat supply sectors.

Tables 6.2 and 6.3 present the weights of domestic energy and non-energy sectors in household expenditures. The units of weight of the energy and non-energy sectors are [PJ/10^9 yen] and [% (= 10^9 yen/10^9 yen)], respectively.

Table 6.2 shows two trends: the progress of electrification and a change in transport fuel from diesel to gasoline. The progress of electrification is driven by all-electric residences and larger household appliances with multiple functions. The shift from diesel to gasoline is caused by factors such as efficient gasoline cars, a tax increase on diesel in 1993, and new emission constraints for air contaminants.

Table 6.3 shows the influence of change in lifestyle, aging society, and protracted recession. The communication and broadcasting services (No. 40), electric machines (No. 28), and medical and social security (No. 43) sectors increased their shares by 1.9%, 0.9%, and 0.9%, respectively. The share of the communication and broadcasting services sector increased due to the widespread acceptance of computer networks in households. The share of the electric machines sector increased due to both new and additional household appliances: new appliances include personal computers and DVD players, and additional appliances include air-conditioners and televisions, where a family owns more than one such application. The share of the medical and social security sector increased because the society is aging. On the other hand, the food products (No. 19), fiber products (No. 20), commerce (No. 34), and services for consumers (No. 46) sectors decreased their shares by 0.9%, 1.3%, 1.3%, and 1.0%, respectively. For the food products and fiber products sectors, domestic goods are substituted by imported goods. For the commerce sector, margin for merchandise has decreased through the analysis period. Strong competitions under deflationary pressure forced the sector to decrease the margin. For the services for consumers sector, consumption for restaurants and

Table 6.1 Names and numbers of each sector in the hybrid I−O tables.

Energy sectors			
No	Name	No	Name
1	Coal	9	Diesel
2	Crude oil	10	Naphtha
3	Natural gas	11	LPG
4	Nuclear	12	Heavy oil
5	Renewable energy	13	Coal product
6	Gasoline	14	Electricity generation
7	Jet fuel	15	Town gas
8	Kerosene	16	Heat supply
Non-energy sectors			
No	Name	No	Name
17	Agriculture, forestry, and fishing	33	Water services and waste disposal
18	Mining	34	Commerce
19	Food products	35	Finance and insurance
20	Fiber products	36	Estate agency
21	Pulp, paper, and wood products	37	Road passenger transport
22	Chemical products	38	Road freight transport
23	Cement products	39	Other transport
24	Steel	40	Communication and broadcasting services
25	Nonferrous metal	41	Civil services
26	Metal products	42	Education and research
27	General industrial machines	43	Medical and social security
28	Electric machines	44	Other public services
29	Transit machines	45	Services for business
30	Precision machines	46	Services for consumers
31	Other manufacturing products	47	Deskwork products
32	Civil engineering	48	Others

Table 6.2 Weight of domestic energy sectors in household expenditures [PJ/10^9 yen].

	1995	2000	2005	2005−1995
Coal	0	0	0	0
Crude oil	0	0	0	0
Natural gas	0	0	0	0
Nuclear	0	0	0	0
Natural energy	0.0002	0.0001	0.0001	−0.0001
Gasoline	0.0037	0.0037	0.004	0.0003
Jet fuel	0	0	0	0
Kerosene	0.0021	0.0022	0.0022	0.0001
Diesel	0.0006	0.0005	0.0003	−0.0003
Naphtha	0	0	0	0.0000
LPG	0.0012	0.001	0.0011	−0.0001
Heavy oil	0	0	0	0
Coal product	0	0	0	0
Electricity generation	0.0035	0.0034	0.0037	0.0002
Town gas	0.0015	0.0015	0.0015	0
Heat supply	0.0001	0.0001	0.0001	0

Table 6.3 Weight of domestic non-energy sectors in household expenditures [%/100].

	1995	2000	2005	2005–1995
Agriculture, forestry, and fishing	0.0145	0.0135	0.0127	–0.0018
Mining	0	0	0	0
Food products	0.1066	0.1050	0.0975	–0.0091
Fiber products	0.0270	0.0197	0.0138	–0.0133
Pulp, paper, and wood products	0.0035	0.0028	0.0017	–0.0017
Chemical products	0.0105	0.0098	0.0096	–0.0009
Pottery, soil, and stone products	0.0015	0.0012	0.0008	–0.0006
Steel	0	0	0	0
Nonferrous metal	0.0008	0.0004	0.0004	–0.0004
Metal products	0.0018	0.0015	0.0012	–0.0006
General industrial machines	0.0003	0.0003	0.0003	0.0001
Electric machines	0.0158	0.0192	0.0246	0.0088
Transit machines	0.0233	0.0191	0.0203	–0.0031
Precision machines	0.0033	0.0036	0.0033	0.0000
Other manufacturing products	0.0175	0.0146	0.0120	–0.0056
Civil engineering	0	0	0	0
Water services and waste disposal	0.0072	0.0078	0.0078	0.0005
Commerce	0.1836	0.1621	0.1709	–0.0127
Finance and insurance	0.0378	0.0378	0.0434	0.0056
Estate agency	0.2072	0.2102	0.2107	0.0034
Road passenger transport	0.0105	0.0090	0.0090	–0.0015
Road freight transport	0.0116	0.0129	0.0133	0.0017
Other transport	0.0289	0.0325	0.0321	0.0031
Communication and broadcasting services	0.0207	0.0352	0.0399	0.0192
Civil services	0.0028	0.0026	0.0029	0
Education and research	0.0216	0.0207	0.0219	0.0003
Medical and social security	0.0244	0.0287	0.0335	0.0091
Other public services	0.0086	0.0066	0.0089	0.0003
Services for business	0.0148	0.0175	0.0165	0.0017
Services for consumers	0.1587	0.1631	0.1484	–0.0103
Deskwork products	0	0	0	0
Others	0.0001	0.0001	0.0001	0

amusement facilities decreased has decreased through the analysis period. This reduction in personal consumption can be explained by a loss of consumer confidence under the protracted recession.

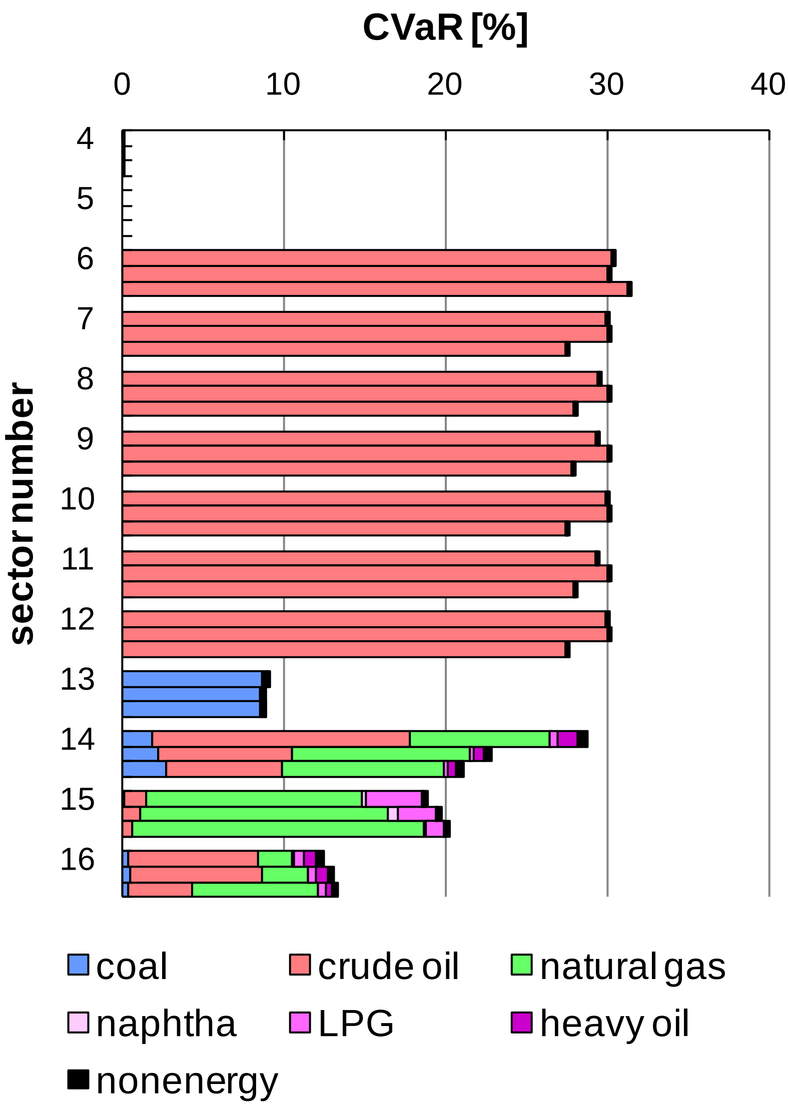
6.3.2. Energy Price Risk of Energy and Industrial Sectors

The CVaR in the energy and non-energy sectors in Japan can be estimated from both the hybrid-unit I–O table and the probabilistic density functions of an increase in the prices of imported energy. Figure 6.2 (a) presents the CVaR in the domestic energy sectors, i.e., a conditional expected value in ΔP^E against a yearly increase in Q^E, decomposed into seven input factors: imported coal, crude oil, natural gas, naphtha, LPG, and heavy oil, and domestic non-energy products. Figure 6.2 (b) presents the decomposition of the CVaR into direct and indirect input factors. The CVaR in the coal, crude oil, and natural gas sectors are not presented because domestic production of these sectors is quite small.

The oil product sectors (Nos. 6–12) have relatively larger CVaR than other energy sectors, because they rely on crude oil, which has a higher energy price risk than coal and natural gas. While the CVaR for almost all oil product sectors decreased during the analysis period, the gasoline sector increased its CVaR. The possible explanation for the decrease in the CVaR during the period 2000–2005 is an improvement in the availability factor. The availability factor of refinery equipment in Japan was 79.4%, 79.1%, and 87.2% in 1995, 2000, and 2005, respectively. On the other hand, the share of gasoline of the total oil production was 22.3%, 25.3%, and 26.3% in 1995, 2000, and 2005, respectively [01]. As the share of gasoline increases, the production of cracked gasoline made from heavy oil fraction must be increased. This change in the share seems to be the cause of the increase in the CVaR of the gasoline sector—cracked gasoline incurs higher costs than crude gasoline.

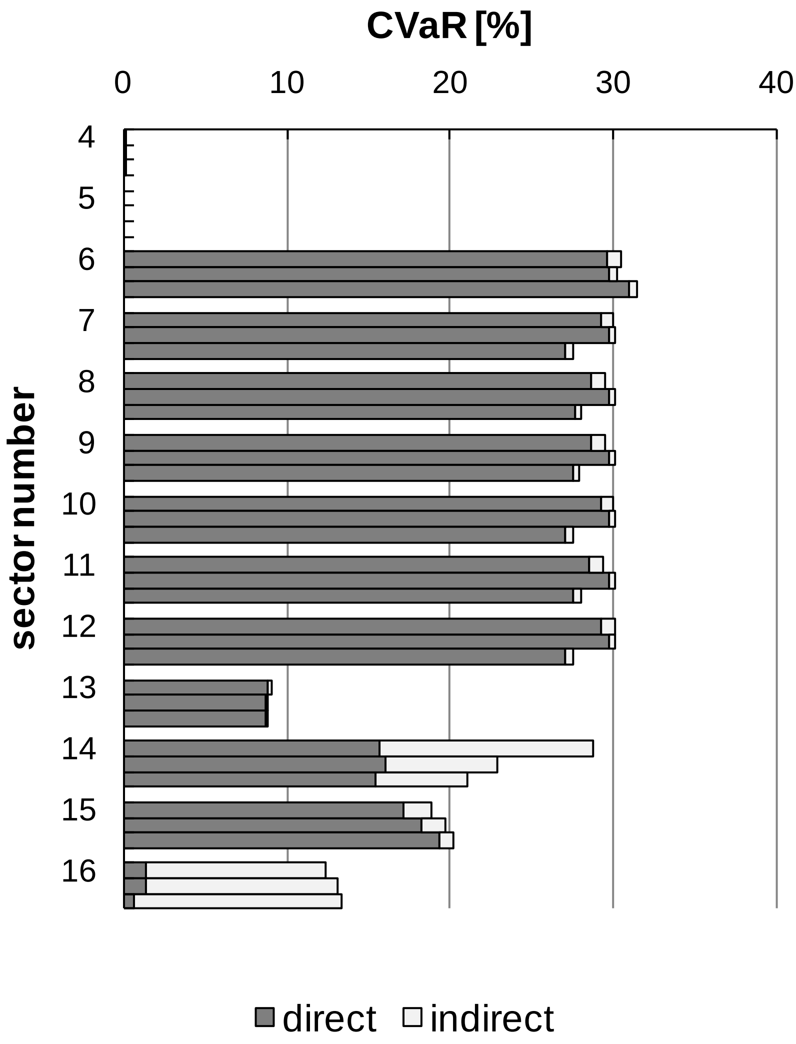
The CVaR of the electricity generation sector (No. 14) becomes much smaller than that of the oil product sectors in 2005, while both exhibit a similar level in 1995. The CVaR in the electricity generation sector decreased by 30% during the analysis period—the most significant contribution to this is a decrease in the input factor of crude oil. Although the share of fossil fuel fired electricity generation of total electricity generation increased from 61.2% in 1995 to 66.1% in 2005, the share of the oil fired electricity generation in fossil fuel fired electricity generation decreased from 31.7% in 1995 to 14.4% in 2005. This substitution of coal and natural gas for oil decreased the energy price risk of the electricity generation sector.

The substitution for oil products with electricity decreased the risk of the



(a)

Figure 6.2 CVaR in the domestic energy sectors (a) decomposed into seven input factors: imported coal, crude oil, natural gas, naphtha, LPG, and heavy oil, and domestic non-energy products. (b) Decomposition of the CVaR into direct and indirect input factors.



(b)

Figure 6.2 (continued)

energy consumers in 2005, because the electricity generation sector has smaller energy price risk than the oil products sector. In addition, the CVaR of the electricity generation sector reached the same level as the town gas sector in 2005, indicating that the substitution electricity for town gas can also decrease the risk of the energy consumers if the CVaR in the electricity generation sector decreases further.

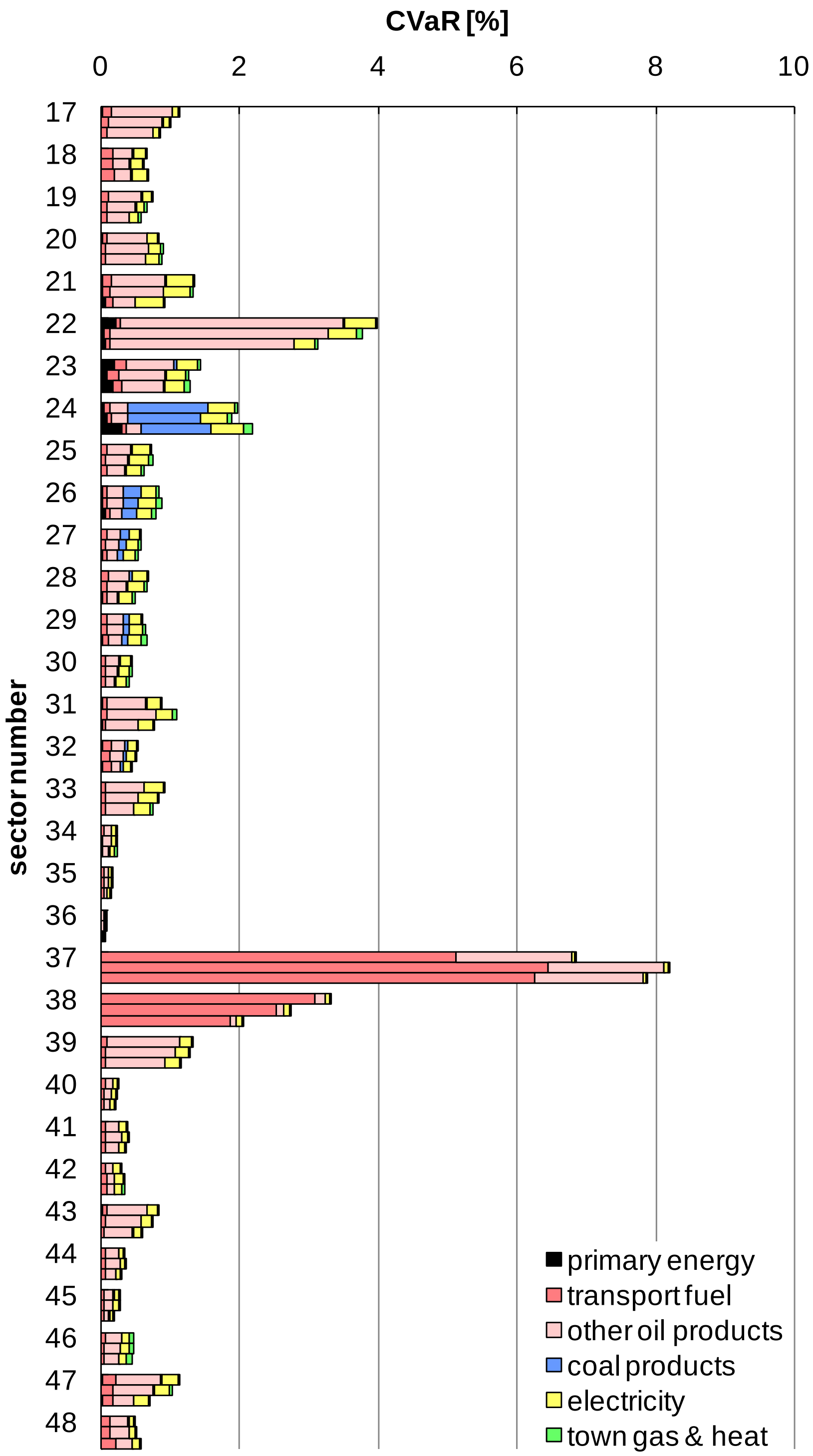
The nuclear (No. 4) and natural energy (No. 5) sectors have little energy price risk, because they seldom use imported fossil fuels for their production.

For all the energy sectors except for the electricity generation and heat supply (No. 16) sector, a large part of the energy price risk is covered by direct input factors. The indirect input factors of the electricity generation and heat supply sectors are inputs of secondary energies such as heavy oil and city gas produced in Japan.

Figure 6.3 (a) shows the CVaR for the non-energy sectors, i.e., the conditional expected value in ΔP^N against a yearly increase in Q^E, decomposed into the input factors of each energy type. In Figure 6.3 (a), the input factors of 16 energy types are aggregated into six factors: the primary energy factor (summation of the input factors of coal, crude oil, natural gas, nuclear, and natural energy), the transport fuel factor (gasoline and diesel), the other oil products factor (jet fuel, kerosene, naphtha, LPG, and heavy oil), the coal product factor, the electricity factor, and the town gas and heat supply factor. Figure 6.3 (b) shows the decomposition of the CVaR into direct and indirect input factors.

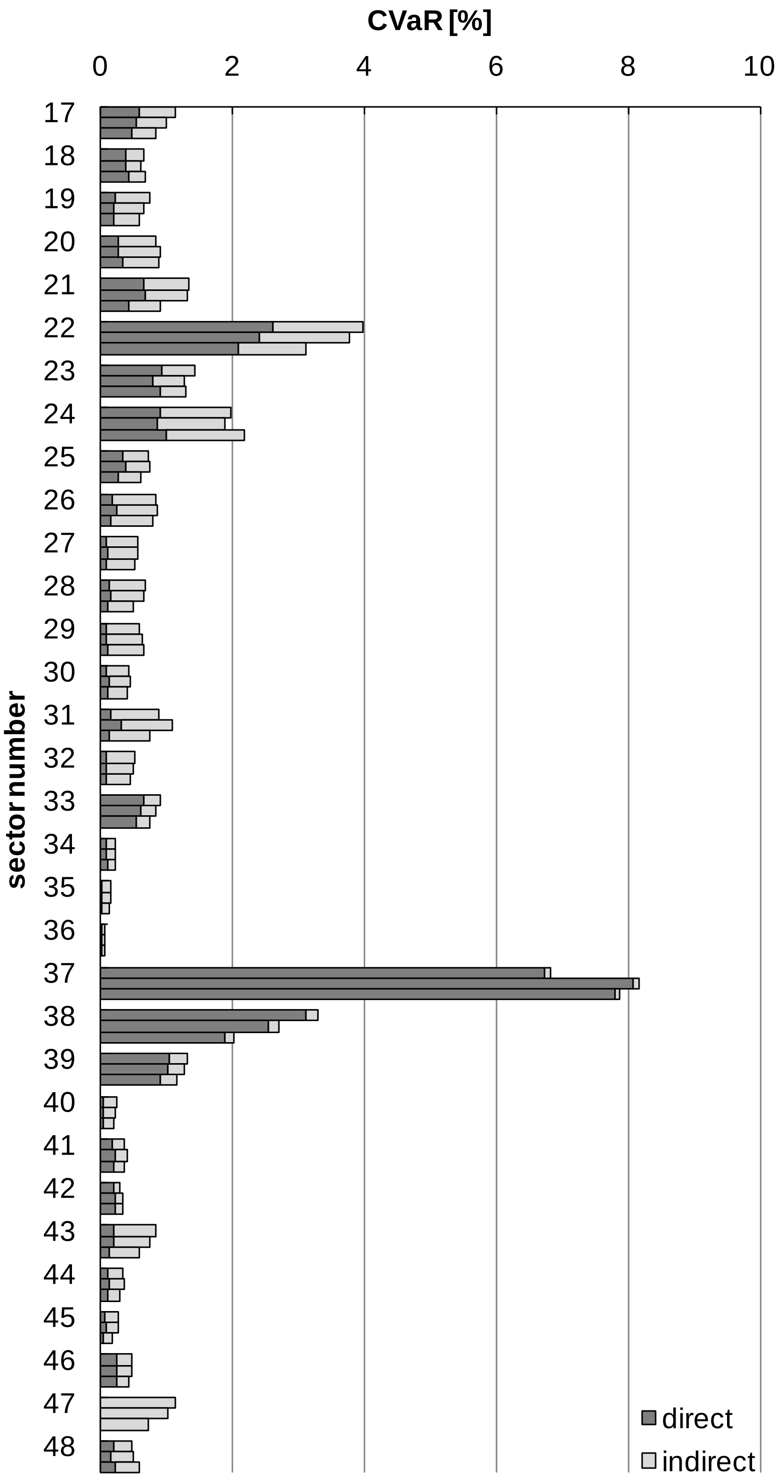
The agriculture sector (No. 17); materials sectors, such as pulp, paper, and wood products (No. 21); chemical products sectors (No. 22); cement products sectors (No. 23); steel sectors (No. 24); and transport sectors (Nos. 37–39) have relatively higher CVaR than other sectors. On the other hand, the assembly sectors, such as metal products (No. 26), general industrial machines (No. 27), electric machines (No. 28), transit machines (No. 29), and precision machines (No. 30) sectors, and service sectors other than transport sectors, have relatively smaller CVaR. In the transport sectors, the CVaR mainly represents the direct input factor; in materials sectors, it covers both direct and indirect input factors; and in the assembly and service sectors; it mainly covers indirect input factors.

Among the material sectors, the pulp, paper, and wood products and chemical products sectors have seen CVaR decrease over the analysis period. Efforts to reduce the direct consumption of oil products, such as enhancement of heat recovery systems, the rise in the availability factor, and the use of waste as fuel, are the reasons for this decrease in the CVaR; as shown in Fig. 6.4 (a) and (b), the main cause of the decrease in the CVaR is the decrease in the input factor of oil products and the direct input factor, respectively. The CVaR for the road passenger transport



(a)

Figure 6.3 CVaR in non-energy sectors. (a) Decomposition into six input factors: the primary energy, transport fuel, other oil products, coal products, electricity, town gas, and heat supply. (b) Decomposition of the CVaR into direct and indirect input factors.



(b)

Figure 6.3 (continued)

sector increased through the analysis period. The energy intensity of buses increased by 1.9% during the period 1995–2000 [01]. This increase in intensity seems to be caused by the substitution of private cars for buses as the mode of transportation; in other words, the decrease in the congestion rate of buses decreased the energy efficiency of the road passenger transport sector. In fact, the traffic volume of buses decreased by 10.3% during the period 1995–2000 while that of private cars increased by 3.3% during the same period [01]. On the other hand, the CVaR for road freight transport and other transport sectors decreased through the analysis period. Measures involving both equipment and systems, such as a decrease in the fuel cost of trucks and improvements in logistical efficiency contributed to the decrease in these risks.

6.3.4. Energy Price Risk of Household Sectors

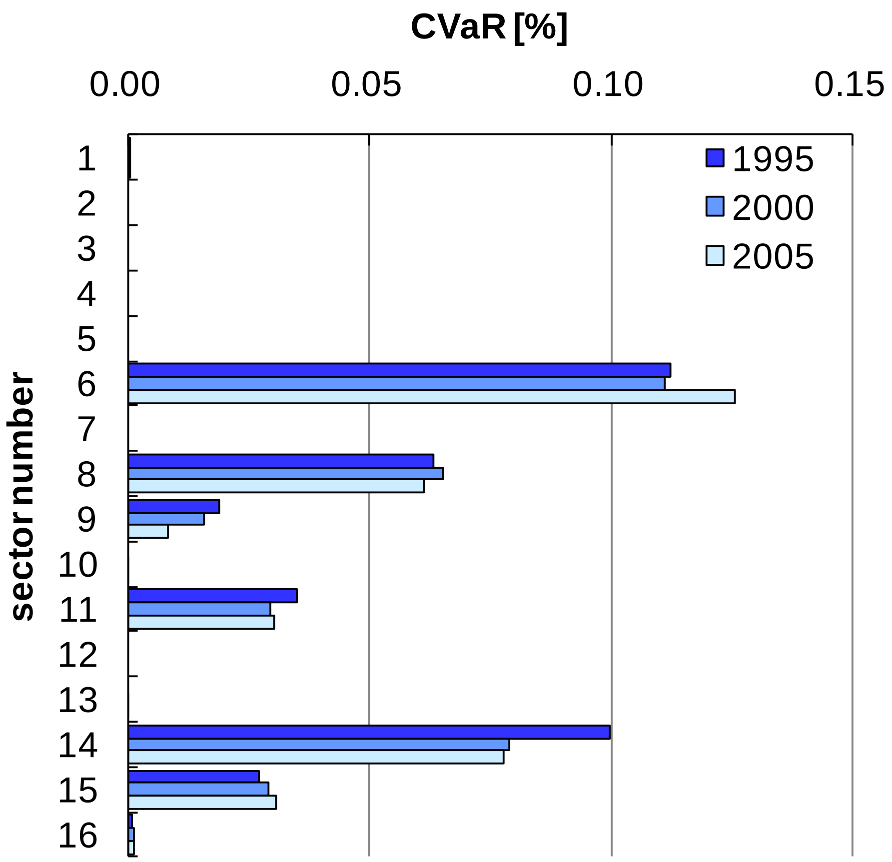
Table 6.4 presents the CVaR in the household sector, estimated from the equation (6-2). The CVaR indicates the expected value of ΔP^H beyond the given level of confidence β, which is set to 95%. The CVaR was 0.9% in 1995, indicating that the household sector in Japan experiences such a magnitude of increase in the expenditure per 20 years. During the period 1995–2005, the CVaR decreased by 0.11points, indicating that the energy price risk in the household sector decreased during this period. The CVaR can be decomposed into the input factors of energy and non-energy products. While the non-energy products comprise a larger input factor than energy products, a large part of the decrease in the CVaR is caused by the decrease in the input factor of non-energy products. The size of error is about 3% by the probability of 99.7%, which is the same level as those in the prices of fossil fuels and producer prices of domestic sectors.

While Table 6.4 presents only the aggregated result of the decomposition, Figure 6.4 (a) and (b) presents the input factors of the energy and non-energy sectors, respectively. Two things can change these input factors: a change in the weight of the household sector or a change in the CVaR in the industrial sector, as shown in the equation (6-2).

For the energy sectors, the top three input factors are gasoline (No. 6), kerosene (No. 9), and electricity generation (No. 14), during the analysis period. While the input factor of gasoline increased, that of electricity generation and diesel decreased. The changes in gasoline and diesel are obvious because both the weight and the CVaR for gasoline increased, and those for diesel decreased. On the other hand, the change in electricity generation sector is interesting, because the weight

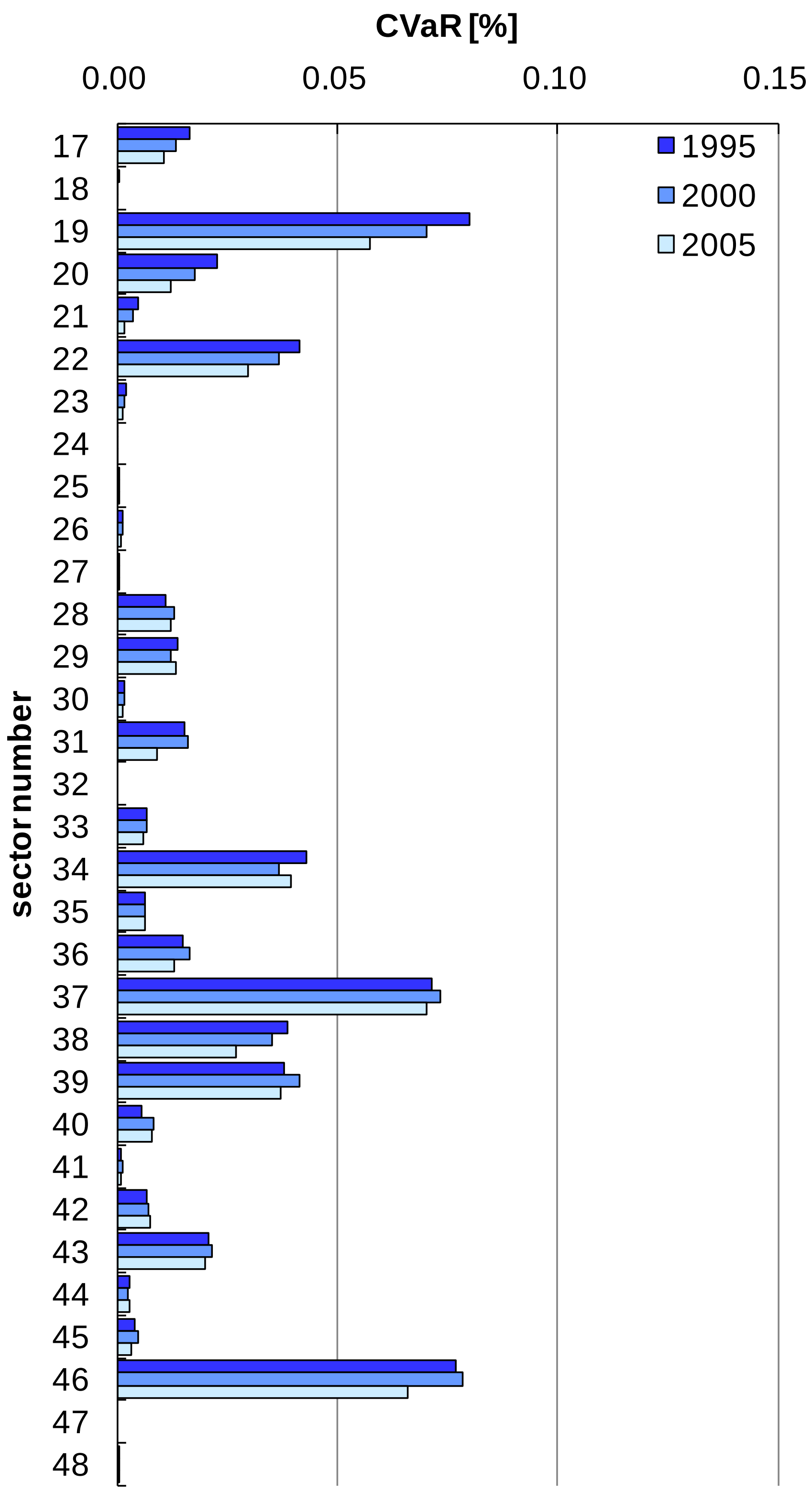
Table 6.4 CVaR in the household sector [%].

	1995	2000	2005	2005–1995
CVaR	0.904	0.858	0.791	−0.113
MEAN/6σ	3.0	3.0	3.0	
Energy	0.357	0.331	0.335	−0.022
Non-energy	0.547	0.527	0.456	−0.091



(a)

Figure 6.4 Result of decomposing the CVaR in the household sector. (a) Input factors of each energy sector. (b)Input factors of each non-energy sector.



(b)

Figure 6.4 (continued)

increased and the CVaR decreased. The result indicates that the household sector decreased its energy price risk from the electricity generation sector regardless of the electrification, because the electricity generation sector decreased its CVaR by changing the energy portfolio from oil to coal and gas.

For the non-energy sectors, the input factors of food products (No. 19), road passenger transport (No. 37), and services for consumers (No. 46) are the top three factors during the analysis period. Chemical products (No. 22), commerce (No. 34), road freight transport (No. 38), and other transport sectors (No. 39) are the third to seventh highest sectors. Among those factors, food products, chemical products, road freight transport, and service for consumers sectors decreased during the period 1995–2005. The decrease in food products, chemical products, and service for consumers sectors are obvious because both the weight and CVaR in these sectors decreased or leveled out. On the other hand, the change in the road freight transport sector is interesting because the weight increased and the CVaR decreased. The result indicates that the reduction in the CVaR in the road freight transport sector was compensated for by an increase in the demand for transportation. In the road passenger transport sector, the sector with the largest input factor in 2005, the input factor did not decrease during the analysis period. While the sector weight decreased, the CVaR increased. These changes may be related: smaller demand for the passenger transport, such as buses, can increase its energy intensity.

From these results, it is clarified that the energy price risk in the household sector decreased during the analysis period in spite of the increasing energy consumption, and there are three causes played an important role in decreasing the risk: development in the energy use of domestic sectors, electrification in the household sector, and the trend toward a service economy.

The CVaR in the producer prices of the electricity generation, chemical products, and road freight transport sectors were decreased through the analysis period. Such a development in the energy use of those sectors contributed to decrease the energy price risk of the household sector.

A decrease in the share of oil in the generation mix and the electrification of the household sector decreased its energy price risk, and can continue to decrease the risk further. Both substituting other fossil fuels for oil and the substitution of nuclear and renewable energy for fossil fuels can decrease the risk. Electrification can decrease the energy price risk of the household sector through the substitution for oil products, because the energy price risk of the electricity generation sector is lower than that of the oil products sector in 2005. In addition, substituting electricity for town gas can also decrease the energy price risk of the household sector if the risk of the electricity generation sector becomes smaller than that of the town gas sector through changes in the generation mix.

The trend to a service economy has contributed to the decrease in the energy price risk in the household sector. This trend includes an increase in the share of sectors with smaller energy price risks, such as electric machines, communication and broadcasting services, and medical and social security sectors. Since CVaR in those sectors are smaller than those in primary and secondary industries, the trend to service economy can decrease the energy price risk of the household sector.

6.4. Discussions

This study develops the framework of I–O portfolio analysis, and quantifies the energy price risk of the household sector in Japan during the period 1995–2005. Furthermore, an index of the risk is decomposed into its constituent parts of various types of input, such as input energy, materials, transport, and service sectors, to clarify the causes of changes in the risk through the analysis period. The results indicate that the energy price risk of the household sector in Japan has decreased through the analysis period in spite of increasing energy consumption. There are three types of changes in the consumption pattern of the household sector, which play an important role in the changes in the risk: development in the energy use, electrification, and the trend toward a service economy.

While this study ignores differences in the income level of households, the difference of the energy price risk among the households with different income levels need to be investigated in the future studies. The consumption portfolio of a household relies on its income level; a household with less income must spend a larger part of its income on basic goods, including energy. Such a household might have a higher energy price risk than a household with a higher income level. According to a working report by OECD [100], the relative poverty ratio and the income gap in Japanese households has increased in the second half of the 1990s. The recent recession triggered by Lehman’s fall might have increased the income gap. Thus, the difference in the income level needs to be investigated before making energy policies to provide a life secure against energy price increases for all the people in Japan.

Chapter 7

Conclusions

This dissertation quantified the energy price risk of domestic sectors in Japan to clarify the cause of the change in energy price risk, and to obtain implications for future energy policy. For the purpose, this dissertation proposes the I–O portfolio analysis that can endogenize all four factors presented in Chapter 1, i.e. difference in the uncertainty among the prices of each type of fossil fuels, primary energy selection by energy conversion sectors, final energy selection by non-energy sectors, and indirect energy consumption relying on national industrial structure.

The I–O portfolio analysis succeeded in explaining a relationship between changes in the energy price risk and domestic industrial structure by applying the single analytical framework. Although some results from the analysis are not new findings, they were separately derived by applying different methods, and presented as different indices in earlier studies. On the other hand, this dissertation presented the same result as earlier studies by applying the single method and single index. This integrated method enables us to compare the energy price risk of different sectors in the same economy, and the same sector in different economies and different time periods. Such a comparison enables us to learn from practical cases in the past and in the other countries, and to transmit the results of succeeded cases to developing countries and regions.

The I–O portfolio analysis also presents some new implications from results. For example, the results of Chapter 5 indicate that the agriculture, forestry, and fishing sector seldom decreased the energy price risk through the period 1970–2000. For agricultural sector, considerable part energy consumption is heavy oil for hating. In other words, this sector has a large potential of decreasing the risk by substituting heavy oil with electricity. Also, the results of Chapter 6 clarified how the trend to a service economy decreases the energy price risk of the household sector in Japan. The electric machines, communication and broadcasting services, and medical and social security sectors increased their shares in the total expenditure of household sector, and contributed to decrease the energy price risk. Such detailed results can be obtained only by applying the I–O portfolio analysis.

Further, the analytical framework of the I–O portfolio analysis can take the technological change in the domestic sectors into consideration. As presented in Chapter 4, the I–O portfolio analysis can quantify an influence of the change in energy portfolio of the electricity generation sector on the energy price risk of domestic sectors. Although the analysis in Chapter 4 only focuses on the change in generation mix under the restriction of existing generation capacity, an influence of introducing new capacity and development of energy efficiency in power plants can also be analyzed by applying the same method. In other words, the I–O portfolio analysis can endogenize both the technological and economical changes.

On the other hand, the GBM model adapted by the I−O portfolio analysis is not a perfect emulation of actual changes in the prices of fossil fuels and CO_2: the actual price distribution has longer upper tail than that of the GBM. Although the extreme price changes in the markets need to be described by the price model in terms of risk analysis, the GBM model cannot describe such extreme price changes. To model extreme price changes in the markets, time series data of market prices with relatively short interval, such as weekly, daily, or hourly, is required. However, such a short-interval data is unavailable for some types of energy, and even if available, the length of data is not enough to estimate long-term characteristics of the markets. For example, the CO_2 market has only time series data whose length is just few years. Such a problem can be solved by developing the method that can estimate long-term characteristics from short-term data.

Based on those discussions, three directions of future developments can be proposed from this dissertation. The first is the detailed analysis of domestic sectors whose energy price risk has not decreased through the decades. Especially, the agricultural sector in Japan is heavily reliant on oil products nevertheless the sector is focused on as one of the drivers of Japanese economy in the future. Then, the present status of energy price risk on the sector needs to be clarified in detail, and the risk reduction effect of substituting oil products with other type of energy needs to be analyzed. Smaller scale and more regional versions of the I–O portfolio analysis can contribute to the purpose. The second is the comparison of sectoral energy price risk among different countries and regions. By clarifying the difference of the risk level and the causes of the risk, policies required for the nations and regions can be found. Because almost all sectors in Japan succeeded in reducing the risk through the decades, the structural changes in the past can be the benchmark for newly developing countries. On the other hand, the difference of energy price risk among regions in Japan is not clarified in this dissertation. Since climatic condition varies among the regions in Japan, the difference of risk among the regions needs to be recognized before making optimal energy policies for each region. The third is to develop the modeling of energy price uncertainty. As discussed above, if the long-term characteristics of energy and CO_2 markets are estimated from the short-term characteristics of them, the long-term analysis of the energy price risk can derive more accurate results. And such a method can contribute to not only the I–O portfolio analysis but also other types of method estimating the present and future energy price risk.

References

[01] The Institute of Energy Economics, Japan (IEEJ), EDMC Handbook of Energy and Economic database in Japan, The Energy Conservation Center, Tokyo, 2009.

[02] J. Fleming, B. Ostdiek. The impact of energy derivatives on the crude oil market. Energy Economics 21, 135–167, 1999.

[03] Y. Nagata. Cause and influence of large fluctuation in the price of crude oil, and the measure to it. Energy Economics Japan, 2010. Available from: http://eneken.ieej.or.jp/en/report_list.php. [in Japanese]

[04] British Petroleum (BP), BP statistical review of world energy 2010. BP website, 2010. Available from http://www.bp.com/.

[05] Ministry of the Environment (MOE). The Current Status of the Emissions Trading Scheme in Japan. MOE website 2009. Available from: http://www.env.go.jp/en/earth/ets/mkt_mech/current-ets.pdf.

[06] Ministry of Internal Affairs and Communications (MIC). Law Data Providing System. Available from: http://law.e-gov.go.jp/cgi-bin/strsearch.cgi. [in Japanese]

[07] Cabinet Secretariat of Japan. Translations of Japanese Laws and Regulations. Available from: http://www.japaneselawtranslation.go.jp/?re=01.

[08] H. Markowitz. Portfolio selection. The Journal of Finance 7 (1), 77–91, 1952.

[09] K. Costello. A perspective on fuel diversity. The Electrical Journal 18(4), 28–47, 2005.

[10] D. Bar-Lev, S. Katz. A portfolio approach to fossil fuel procurement in the electric utility industry. The Journal of Finance 31(3), 933–947, 1976.

[11] H.B. Humphreys, K.T. McClain. Reducing the impacts of energy price volatility through dynamic portfolio selection. The Energy Journal 19(3), 107–131, 1998.

[12] S.H. Lesbirel, Diversification and energy security risks: the Japanese case. Japanese Journal of Political Science 5(1), 1–22, 2004.

[13] W.F. Sharpe. A simplified model for portfolio analysis. Management Science 9, 277–293, 1963.

[14] T. Hattori. An application of portfolio theory to fuel choice in Japanese electricity industry. Proceedings of the first IAEE Asian Conference, 1–29, 2007.

[15] G. Wu, L.C. Liu, Y.M. Wei. Comparison of China's oil import risk: results based on portfolio theory and a diversification index approach. Energy Policy 37. 3557–3565, 2009.

[16] M. Liu, F.F. Wu. Risk management in a competitive electricity market. Electrical Power and Energy Systems 29, 690–697, 2007.

[17] Z. Yu. Spatial energy market risk analysis using the semivariance risk measure. Electric power and energy systems 29, 600–608, 2007.
[18] L. Bartelj, D. Parevan, A.F. Gubina, R. Golob. Valuating a risk from sales contract offer maturity in electricity market. International Journal of Electrical Power & Energy Systems 32 (2), 147–155, 2010.
[19] S.J. Deng, L. Xu. Mean-risk portfolio analysis of demand response and supply resources. Energy 34, 1523–1529, 2009.
[20] S. Awerbuch, M. Berger. Applying portfolio theory to EU electricity planning and policy-making. International Energy Agency, Paris, France, 2003. Available from: http://www.awerbuch.com/shimonpages/shimondocs/iea-portfolio.pdf.
[21] J.C. Jansen et al. Application of portfolio analysis to the Dutch generating mix. Energy research Centre of the Netherland, Petten, Netherland, 2006. Available from: http://www.ecn.nl/docs/library/report/2005/c05100.pdf.
[22] Y.H. Huang, J.H. Wu. A portfolio risk analysis on electricity supply planning. Energy Policy 36, 627-641, 2008.
[23] S. Awerbuch. Portfolio-based electricity generation planning: policy implications for renewables and energy security. Mitigation and Adaption Strategies for Global Change 11, 693–710, 2006.
[24] I. Fortin, S. Fuss, J. Hlouskova, N. Khabarov, M. Obersteiner, J. Szolgayova. An integrated CVaR and real options approach to investments in the energy sector. The Journal of Energy Markets 1 (2), 61–85, 2008.
[25] F.A. Roques, D.M. Newbery, W.J. Nuttall. Fuel mix diversification incentives in liberalized electricity markets: A Mean-Variance Portfolio theory approach. Energy Economics 30, 1831–1849, 2008.
[26] Ministry of Economy, Trade and Industry (METI), White Paper on Energy 2006, Available from: http://www.enecho.meti.go.jp/topics/hakusho/2006EnergyHTML/index.html. [in Japanese]
[27] Y. Yuasa, Y. Uchiyama. Analysis of instability of fossil fuel supply by using portfolio analysis and input–output analysis. Bulletin of Department of Risk Engineering 2, 24–31, 2006. Available from: http://www.risk.tsukuba.ac.jp/riskhp08/ext/bulletin/vol2/risk-kiyou-2-allt.pdf. [in Japanese]
[28] W.F. Sharpe. Portfolio theory and capital markets. McGraw-Hill, New York, 1970.
[29] Japan Tariff Association (JTA). Japan Exports & Imports. 1970.1–2006.3. [in Japanese]
[30] B.T. Ewing, F. Malikb, O. Ozfidan. Volatility transmission in the oil and natural gas

markets. Energy Economics 24, 522–538, 2002.
[31] P. Giot, S. Laurent. Market risk in commodity markets: a VaR approach. Energy Economics 25, 435–457, 2003.
[32] Z. Yu. Spatial energy market risk analysis using the semivariance risk measure. Electric power and energy systems 29, 600–608, 2007.
[33] Agency for Natural Resources and Energy (ANRE). Overview of electricity demand and supply. Chuwa printing co. Ltd., Tokyo, 1971–2006. [in Japanese]
[34] ANRE, General Energy Statistics, Available from: http://www.enecho.meti.go.jp/info/statistics/jukyu/index.htm. [in Japanese]
[35] E. Regnier. Oil and energy price volatility. Energy Economics 29. 405–427, 2007.
[36] Bank of Japan website. http://www.boj.or.jp/en/theme/stat/index.htm.
[37] W. Leontief. Quantitative input and output relations in the economic system of the United States. The Review of Economic Statistics 18 (3), 105–125, 1936.
[38] W. Leontief. Input–output Economics. Oxford University Press, New York, 1966.
[39] C.W. Bullard, R.A. Herendeen. The energy cost of goods and services. Energy Policy 3, 268–278, 1975.
[40] R.E. Miller, P.D. Blair. Input–output Analysis: Foundations and Extensions. Prentice-Hall, New Jersey, 1985.
[41] J.L.R. Proops, M. Faber, G. Wagenhals. Reducing CO_2 Emissions. Springer–Verlag, Berlin, Germany, 1993.
[42] M. Lenzen. Primary energy and greenhouse gases embodied in Australia final consumption: an input–output analysis. Energy Policy 26, 495–506, 1998.
[43] S.Y. Han, S.H. Yoo, S.J.Kwak. The Role of the Four Electric Power Sectors in the Korean National Economy: an Input–output Analysis. Energy Policy 32, 1531–1543, 2004.
[44] S.H. Yoo, T.H. Yoo. The role of the nuclear power generation in the Korean national economy: an Input–output analysis. Progress in Nuclear Energy 51, 86–92, 2009.
[45] H. Berument, H. Taşçi. Inflationary Effect of Crude Oil Prices in Turkey. Physica A 316, 568–580, 2002.
[46] K.Q. Nguyen. Impacts of a rise in electricity tariff on prices of other products in Vietnam. Energy Policy 36, 3145–3149, 2008.
[47] T. Hattori, Y. Matsue. Influence of soaring oil prices on the Japanese industrial prices. Central Research Institute of Electric Power Industry, Socio-economic Research Center Research Paper Rep.No.Y05013, 1–41, 2006. [in Japanese]
[48] K. Fujikawa, M. Shimoda, T. Watanabe. A competitive analysis on ripple effect of imported oil price hike in domestic prices between Japan and USA. Journal of

Socio Economic Research 55, 45–62, 2007. [in Japanese]
[49] X. Labandeira, J.M. Labeaga. Estimation of Spanish energy-related CO_2 emissions: an input–output approach. Energy Policy 30, 597–611, 2002.
[50] J. Choi, B.R. Bakshi, T. Haab. Effects of a carbon pricenext term in the U.S. on economic sectors, resource use, and emissions: An input–output approach. Energy Policy 38, 3527–3536, 2002.
[51] M. Llop, L. Pié. Input–output Analysis of Alternative Policies Implemented on the Energy Activities: An application for Catalonia. Energy Policy 36, 1642–1648, 2008.
[52] H.T. Liu, J.E. Guo, D. Qian, Y.M. Xi. Comprehensive evaluation of household indirect energy consumption and Impacts of alternative energy policies in China by input–output analysis. Energy Policy 37, 3194–3204, 2009.
[53] M. Llop. Economic impact of alternative water policy scenarios in the Spanish production system: An input–output analysis. Ecological Economics 68 (1-2), 288–294, 2008.
[54] C. Lian, J.R. Santos, Y.Y Haimes. Extreme risk analysis of interdependent economic and infrastructure sectors. to appear in Risk Analysis. Risk Analysis 27 (4), 1053–1064, 2007.
[55] J.R. Santos. Interdependency analysis with multiple probabilistic sector inputs. Journal of Industrial and Management Optimization 4 (3), 489–510, 2008.
[56] J.R. Santos, Y.Y. Haimes, C. Lian. A framework for linking cybersecurity metrics to the modeling of macroeconomic interdependencies. Risk Analysis 27 (5), 1283–97, 2007.
[57] J.R. Santos, K. Barker, P.J. Zelinke IV. Sequential Decision-making in Interdependent Sectors with Multiobjective Inoperability Decision Trees: Application to Biofuel Subsidy Analysis. Economic Systems Research 20 (1), 29–56, 2008.
[58] J. Defourny, E. Thorbecke. Structural path analysis and multiplier decomposition within a social accounting matrix framework. The Economic Journal 94, 111–136, 1984.
[59] G.J. Treloar. Extracting embodied energy paths from input–output tables: towards an input–output-based hybrid energy analysis method. Economic Systems Research 9 (4), 375-391, 1997.
[60] M. Lenzen. Environmentally Important Paths, Linkages and Key Sectors in the Australian economy. Structural Change and Economic Dynamics 14, 1–34, 2003.
[61] S. Suh. Theory of Materials and Energy Flow Analysis in Ecology and Eco-nomics. Ecological Modeling 189, 251–269, 2005.

[62] G.P. Peters, E. G. Herwich. The Importance of Imports for Household Environmental Impacts. Journal of Industrial Ecology 10 (3), 89–109, 2006.
[63] M. Lenzen, T. Wiedmann, B. Foran, C. Dey, A. Widmer-Cooper, M. Williams, R. Ohlemüller. Forecasting the Ecological Footprint of Nations: a Blueprint for a Dynamic Approach. ISA, The University of Sydney, Sydney, 2007.
[64] S. Suh. Functions, Commodities and Environmental Impacts in an Ecologi-cal-Economic Model. Ecological Economics 48, 451–467, 2004.
[65] M. Lenzen. Structural Path Analysis of Ecosystem Networks. Ecological Modeling 200, 334–342, 2007.
[66] C. Batlle, J. Barquı´n. Fuel prices scenario generation based on a multivariate GARCH model for risk analysis in a wholesale electricity market. Electrical Power and Energy Systems 26, 273–280, 2004.
[67] A. Worthington, A. Kay-Spratley, H. Higgs. Transmission of prices and price volatility in Australian electricity spot markets: a multivariate GARCH analysis. Energy Economics 27, 337–350, 2005.
[68] H. Mohammadi, L. Su. International evidence on crude oil price dynamics: Applications of ARIMA-GARCH models. Energy Economics 32, 1001–1008, 2010.
[69] T. Bollerslev. Generalized Autoregressive conditional heteroskedasticity. Journal of Economics 31, 307–327, 1986.
[70] P. Norouzzadeh, W. Dullaertc, B. Rahmani. Anti-correlation and multifractal features of Spain electricity spot market. Physica A 380, 333–342, 2007.
[71] J. Alvarez-Ramirez, J. Alvarez, E. Rodriguez. Short-term predictability of crude oil markets: A detrended fluctuation analysis approach. Energy Economics 30. 2645–2656, 2008.
[72] S. Engelen, P. Norouzzadeh, W. Dullaert, B. Rahmani. Multifractal features of spot rates in the Liquid Petroleum Gas shipping market. Energy Economics, doi:10.1016/j.eneco.2010.05.009, 2010.
[73] S. Fuss, J. Szolgayova, M. Obersteiner, M. Gusti. Investment under market and climate policy uncertainty. Applied Energy 85, 708–721, 2008.
[74] T. Nakawiro, S.C. Bhattacharyya, B. Limmeechokchai. Electricity capacity expansion in Thailand: An analysis of gas dependence and fuel import reliance. Energy 33, 712–723, 2008.
[75] F.A.S. Postali, P. Picchetti. Geometric Brownian Motion and structural breaks in oil prices: A quantitative analysis. Energy Economics 28, 506–522, 2006.
[76] A. Dixit, R. Pindyck. Investment under uncertainty. Princeton: Princeton University Press; 1994.

[77] Zhou W, Zhu B, Fuss S, Szolgayová J, Obersteiner M, Fei W. Uncertainty modeling of CCS investment strategy in China's power sector. Applied Energy 87, 2392–2400, 2010.
[78] Szolgayová J, Fuss S, Khabarov N, Obersteiner M. A dynamic CVaR-portfolio approach using real options: an application to energy investments. European Transactions on Electrical Power 2010; doi:10.1002/etep.429.
[79] P. Artzner, F. Delbaen, J.M. Eber, D. Heath. Thinking Coherently. Risk 10 (11), 68–71, 1997.
[80] P. Artzner, F. Delbaen, J.M. Eber, D. Heath. Coherent Measures of Risk. Mathematical Finance 9 (3), 203–228. 1999.
[81] R. Rockafellar, S. Uryasev. Conditional value at risk. Journal of Risk 2 (3), 21–42, 2000.
[82] Japan Iron and Steel Federation (JISF). Taking action to fight global warming based on the voluntary action program. 3-2-10, Nihonbashi-Kayabacho, Chuo-ku, Tokyo, 2009. Available from: http://www.jisf.or.jp/en/statistics/sij/docs/EnergyandtheEnvironment.Recycle.pdf.
[83] Kossoy A, Ambrosi P. State and Trends of the Carbon Market. The World Bank 2010. Available from: http://siteresources.worldbank.org/INTCARBONFINANCE/Resources/State_and_Trends_of_the_Carbon_Market_2010_low_res.pdf.
[84] L. M. Abadie, J. M. Chamorro. European CO_2 prices and carbon capture investments. Energy Economics 30, 2992–3015, 2008.
[85] Söderholm P. Fuel flexibility in the West European power sector. Resource Policy 26, 157–70, 2000.
[86] Tauchmann H. Firing the furnace? An econometric analysis of utilities' fuel choice. Energy Policy 34, 3898–909, 2006.
[87] ANRE. Summary of electric power supply and demand 2005. Chuwa printing co., Ltd.: Tokyo; 2006.
[88] G. Ruhe. Algorithmic aspects of flows in networks. Kluwer Academic Publishers, Dordrecht, pp. 63–79, 1991.
[89] Federation of Electric Power Companies (FEPC). Hand book of electric power industry 2008. Japan Electric Association, Tokyo, 2008.
[90] S. Ashina, J. Fujino. Simulation analysis of CO2 reduction scenarios in Japan's electricity sector using multi-regional optimal generation planning model. Journal of Japanese Society of Energy and Resources 29 (1), 1–7, 2008. [in Japanese]
[91] Ministry of Internal Affairs and Communications (MIC). Input–output Tables 2005. MIC website 2009, Available from:

http://www.e-stat.go.jp/SG1/estat/List.do?bid=000001019588&cycode=0. [in Japanese]
[92] European Climate Exchange (ECX) Website: http://www.ecx.eu/.
[93] International Institute of Applied System Analysis (IIASA). GGI scenario database 2007. Available from: http://www.iiasa.ac.at/web-apps/ggi/GgiDb/.
[94] K. Kawashima. A quantitative analysis of energy security using TSIO. Research Report for Agency for Natural Resources and Energy, Institute of Energy Economics, Tokyo, 55–115, 2005. [in Japanese]
[95] ANRE. Yearbook of mineral resources and petroleum products statistics. 1970–2000. Available from: http://www.meti.go.jp/statistics/tyo/seidou/. [in Japanese]
[96] Sekiyu-Kagaku-Sinbun-Sha. Yearbook of petrochemical industry. 2-4-10,Iwamotocho,Chiyoda-ku,Tokyo. 1970–2000. [in Japanese]
[97] ANRE, 1995, 2000, and 2005 Energy Balance Table. ANRE website: http://www.enecho.meti.go.jp/info/statistics/jukyu/result-2.htm. [in Japanese]
[98] Ministry of Internal Affairs and Communications (MIC), 1995–2000–2005 Linked Input–output Tables, Statistics Bureau, Director-General for Policy Planning and Statistical Research and Training Institute, Tokyo, 2010.
[99] Ministry of Internal Affairs and Communications (MIC), 1995, 2000, and 2005 quantity Input–output Tables. Statistics Bureau, Director-General for Policy Planning and Statistical Research and Training Institute, Tokyo, 1999, 2004, 2009.
[100] M. Förster, M.M. d'Ercole, Income Distribution and Poverty in OECD Countries in the Second Half of the 1990s. OECD Social, Employment and Migration Working Paper 22, 2005. Available from: www.oecd.org/els/workingpapers.

Publications

1. Reviewed Journal Papers

[J1] Kengo Suzuki, Daisuke Masukawa, Yohji Uchiyama, Risk in the Prices of Fossil Fuels for Japanese Electric Utility Sector, Journal of Energy and Power Engineering 4, 9–16, 2010.
[J2] Kengo Suzuki, Yohji Uchiyama, Quantifying the risk of an increase in the prices of non-energy products by combining the portfolio and the input–output approaches, Energy Policy 38, 5867–5877, 2010.
[J3] Kengo Suzuki, Yohji Uchiyama, Analysis of the price fluctuation risk of imported crude oil by applying the portfolio theory, Journal of Japan Society of Energy and Resources 2008, 29, 14–20 [in Japanese].
[J4] Kengo Suzuki, Yohji Uchiyama, Quantifying Risk of Energy Cost Volatility in Demand Side, Applied Energy (submitting).
[J5] Kengo Suzuki, Yohji Uchiyama, Quantifying the energy price risk of household sector in Japan, Energy Conversion and Management (submitting).

2. Reviewed Conference Proceedings

[C1] Kengo Suzuki, Daisuke Masukawa, Yohji Uchiyama, Mean-Semivariance Model for Energy Security Analysis: A Case Study of Japanese Electric Utility Sector, The First International Conference on Applied Energy, Paper No: ICAE09_132, Hong Kong, China (January 2009).
[C2] Kengo Suzuki, Yohji Uchiyama, Quantifying Risk of Energy Cost Volatility in Demand Side, The Second International Conference on Applied Energy, Singapore (April 2010).

3. Nonreviewed Conference Proceedings

[N1] Kengo Suzuki, Yohji Uchiyama, An Analysis of Japanese Energy Security against Simultaneous Price Shocks in Imported Fossil Fuels, Second International Association of Energy Economics Asian Conference, Session 3 (4th Speaker), Perth, Australia (November 2008).
[N2] Daisuke Masukawa, Kengo Suzuki, Yohji Uchiyama, Optimal generation planning model of CVaR by a real options method, Proceedings of the 26th Energy Sys-tem,

Economics, and Environment Conference, Paper No: 26–3, Tokyo (January 2010). [in Japanese]
[N3] Kengo Suzuki, Yohji Uchiyama, An impact of increases in prices of fossil fuels on domestic price index, and key sectors to mitigate the impact, Proceedings of the 25th Energy System, Economics, and Environment Conference, Paper No: 8–1, Tokyo (January 2009). [in Japanese]
[N4] Kengo Suzuki, Yohji Uchiyama, Research of inflationary effect by crude oil price appreciation using network structure analysis between industries, Proceedings of the 24th Energy System, Economics, and Environment Conference, Paper No: 5–2, Tokyo (January 2008). [in Japanese]
[N5] Daisuke Masukawa, Kengo Suzuki, Yohji Uchiyama, Analysis of price fluctuation risk of imported fossil fuel by applying the portfolio theory, Proceedings of the 24th Energy System, Economics, and Environment Conference, Paper No: 30–1, Tokyo (January 2008). [in Japanese]
[N6] Kengo Suzuki, Yohji Uchiyama, Analysis of the price fluctuation of imported fossil fuels by applying Portfolio Theory, Proceedings of the 23th Energy System, Economics, and Environment Conference, Paper No: 30–4, Tokyo (January 2007). [in Japanse]
[N7] Kengo Suzuki, Koji Shimizu, Katsuhiko Someya, Hideki, Kakeya, Current status of the privacy, Proceedings of Trustability & Anti-Crime Technology workshop 2006, pp9–17 , Tokyo (December 2006). [in Japanese]

4. Other Articles

[O1] Kengo Suzuki, The true barrier for internationalization of Japan, Bulletin of Department of Risk Engineering, 7, in press (March 2011). [in Japanse]
[O2] Kengo Suzuki, The conversation stressing the contents, Bulletin of Department of Risk Engineering, 5, pp59–63 (March 2009). [in Japanse]

Acknowledgements

I am most grateful for Professor Yohji Uchiyama who is my supervisor. He allowed me to join his laboratory, and have helped my study and work to develop my ability for research and education. Without a free climate of the Uchiyama laboratory managed by him, I could not have developed my ability and completed this doctoral dissertation.

I am grateful for Professor Keiichi Okajima who is my second advisor. He gave me many pieces of advices about research, laboratory life, and other things, and always encouraged my study and work.

I am grateful for Professor Yuko Hatano who always cheered my research and study. As other students, I am strongly encouraged by her bright character.

I am grateful for Professor Hidetoshi Konno who taught me basic knowledge about mathematical modeling. Through his lecture, I could get over fear for the mathematical modeling, and learned what we should attend to when analyzing natural and social phenomena.

I am grateful for Professor Gaku Shoji who gave me sharp comments about the dissertation. His comments developed the analyses and discussions in this dissertation.

Colleagues of the Uchiyama and Okajima laboratories have helped me a lot through discussions about researches. Especially, discussions in the seminar could not have been enriched without their cooperation.

DALI, a small but cozy saloon near our university, helped my university life a lot. Discussions and chats with staffs and regulars of DALI changed my mindset and gave me new inspirations. Especially, researchers and doctoral students among them gave me many pieces of insights and advices.

Finally, I would like to thank my family for their supports through many years.