A QUANTITATIVE ANALYSIS OF MARKET OPPORTUNITY UTILIZATION IN ELECTRIC POWER COMPANIES

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Abstract: In EU countries and several states in the U.S., the wholesale power markets are well developed enough to be utilized by many electric power companies. These companies usually have a trading division which intensively handles all of transactions with fuel and power markets standing between generation and retail divisions, even if they were vertically integrated before liberalization. This study quantitatively evaluates the effects of potential use of market opportunities through the trading division, and compare them under different conditions and constraints. Then we clarify the problem that under which price conditions in the future the trading function will work effectively.

Keyword: electric power market**,** trading mechanism, internal transaction, profit maximization, SBM-max model

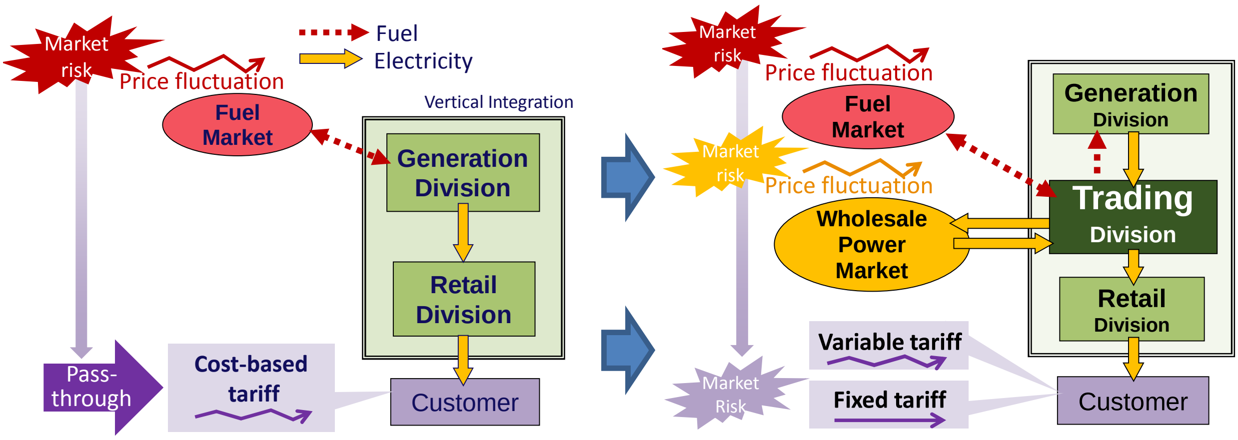
1. INTRODUCTION

The System Reform in the electricity industry is now underway in Japan, for instance, the retail electricity markets for domestic customers will be opened in April, 2016. Government expects that the Reform will promote new entries, result in revitalizing the competition in the electricity market. Along with this, it is also expected that the wholesale power market will be revitalized, even though the liquidity has been very limited since it was established in 2005.

In EU countries and several states in the U.S., electricity retail markets were already opened and also the liquidity of wholesale power markets has been much higher than that in Japan. In their countries and states, it is common for power companies to utilize a wholesale market through "trading function". Although some companies own trading function as a department, others have a subsidiary company for trading, the basic functions are same among them. In this study, we refer to the organization which has trading function in the company as a "trading division" or "TD" hereinafter.

In Japan, electric power companies have been vertically integrated, and the generation division (GD) has sent the most of generated electricity to the retail division (RD) directly as a matter of course. However, it will be changed in accordance with the increase of the market liquidity in the wholesale power market. Actually, some power companies are attempting to establish TD in preparation for effective use of market opportunities. On the other hand, others are skeptical about utilization of market mechanisms and the effects of TD.

This study attempts to quantitatively clarify the effect



1a: Before liberalization **1b:** After liberalization

Figure 1: Change of the internal transaction of electricity in the power companies

of utilizing market opportunities through TD. Market prices are fluctuating from moment to moment and it is basically difficult to precisely predict them. However, we can simulate the effect of the price fluctuation and prepare for it. In this study, we examine under what price condition in the future the trading function will effectively work.

This paper unfolds as follows. In Section 2, we summarize how the electricity internal transaction system in power companies in EU and U.S changed between before and after liberalization. Then, in Section 3, the framework of quantitative analysis is explained in order to clarify the effect of trading function. The results are shown in Section 4 and some remarks follow in the last section.

2. TRADING FUNCTION IN POWER COMPANY

Before liberalization of the electric power industry in many countries including Japan, typical electric power companies were vertically integrated, which has several functions inside one company such as generation, transmission, distribution and retail functions. It was quite common for these companies to internally transmit generated electricity to the retail division (Figure 1a).

However, after liberalization, as wholesale power markets were gradually developed in several countries in EU, the representative power companies established TD in order to sell and buy electricity at the market effectively on behalf of GD and RD (Figure 1b). This enables the whole (parent) company to concentrate various market risk management to the TD on the one-stop basis.

Moreover, referring to market prices, TD procures fossil fuels for generation as well as instructs economic load dispatch to optimize operation of the whole generation assets through fuel and power trading based on profit maximization. This means that, GD produces electricity only when they can make profit. For instance, when fuel prices are high while a power price is relatively low, TD will decide to purchase electricity from the market to cover the final demand in RD instead of ordering GD to produce electricity at its own power plants.

In this market-oriented system (referred to as “MO system” hereinafter), there is no direct transaction between GD and RD, which is completely different from the vertically integrated system before liberalization (referred to as “VI system” hereinafter). The difference is attributable to the volume and price constraints on the internal transaction as follows.

➢ Volume constraint:

In the VI system, all of the electricity demand in RD is covered by electricity generated at power plants in GD. In other words, the volume of the internal transaction is strictly constrained, while it is completely free in the MO system, i.e. TD can freely choose sources of electricity from the power market and/or the internal transaction in order to cover the final demand in RD.

➢ Price constraint:

In the traditional VI system, the transfer price of the internal transaction is based on generation cost, while in the MO system, it is decided based on market prices. In the market mechanism, prices depend on supply and demand, not based on cost. Therefore, in this situation, the cost-based price setting in the VI system can be regarded as a strict constraint.

This study compares these two systems and clarifies the effects of trading function from the three points of view as follows:

A. Profit (return):

If a power company effectively utilize the fuel and power markets in the MO system, total profit of the company will be maximized rather than depending on the internal transaction in the VI system. In other words, the strict volume and price constraints may inhibit the profit maximization of the company.

B. Stability of the profit (risk)

However, the company will be exposed by market risks in the MO system.

C. Competitiveness

If the company utilizes the market price for the internal transfer price, the profit will be optimized, but the competitiveness in the retail market may be reduced, because it cannot make differentiation of retail prices among competitors. In the VI system, the cost-based internal price may have advantage over the MO system, especially in the case the company own inexpensive power plants such as a hydro power plant. In this study, we employ the retail price level as a competitive index. We assume the lower price can enhance competitiveness of the company.

In general, high-risk case could bring high return, and higher competitiveness (lower retail price level) could fall into lower profit. In other words, these three factors listed above would bring different evaluation even under the same condition. In such case, DEA will be a very powerful method to conduct comprehensive evaluation based on multi-factors. So, in this study, we apply the SBM-max model (Tone, 2015) to evaluate the VI and MO systems under several market price conditions.

3. MEASURING THE EFFECT OF TRADING FUNCTION

In this section, we explain how to measure the effect of trading function under different conditions.

3.1. Definition of transaction volumes and prices

Figure 2 summarizes the electricity transactions in a typical power company after liberalization, where notations in the parentheses indicate electricity volume and price.

➢ Generation division (GD)

We postulate GD owns gas and coal fired, and hydro power plants. G_{it}^{e} is actually consumed fuel measured by kWh in period t (t = 1,…,T)[1], where "i" indicates the type of power plants (i = gas, coal and hyd). Each power plant cannot generate electricity over the capacity ($\overline{G}_i^{e}$).

$$G_{it}^{e} \le \overline{G}_i^{e} \qquad (1)$$

p_{it}^{w} is a fuel price, which is, in this study, defined as a market price fluctuating on a moment-to-moment basis

[1] The unit of time period "t" can be minute, hour, day, and so on.

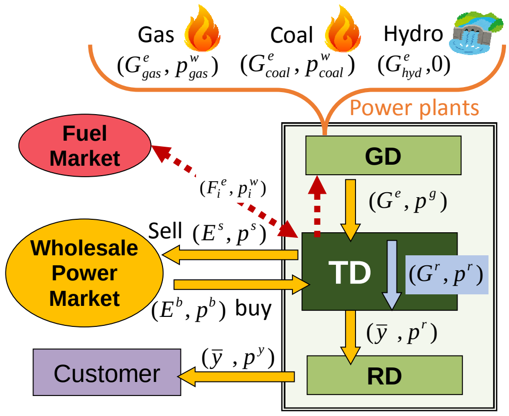


Figure 2: Transaction volumes and prices

for gas and coal, while a price for hydro power is 0. Total generated power and an average generation (fuel) cost are measured based on the actually consumed volume as

$$G^e_t = \sum_i G^e_{it}, \quad p^w_t = \frac{\sum_i p^w_{it} G^e_{it}}{G^e_t}. \tag{2}$$

The decision to generate electricity or not in GD is made by TD at different times referring to fuel and power market prices.

➢ Internal transaction (GD → TD)

All of generated power (G^e_t) is transmitted from GD to TD at the internal transfer price (p^g), which is defined as an average of p^w_t during T periods as

$$p^g = \sum_t \frac{p^w_t}{T}. \tag{3}$$

➢ Trading division (TD)

TD sells generated electricity at plant i to the power market (E^s_{it}) at the market sell price (p^s_t) and/or sent to RD (G^r_{it}) at the transfer price (p^r_t), whose definition will be appeared later in Eq. (6).

$$G^e_t = \sum_i E^s_{it} + \sum_i G^r_{it} = E^s_t + G^r_t \tag{4}$$

TD also has to procure electricity to cover all of the retail demand in RD ($\bar{y}$). TD decides the purchasing volume from the market (E^b_t) and the generated volume at the power plants (G^r_t) based on the fuel and power market prices.

$$\bar{y} = E^b_t + \sum_i G^r_{it} = E^b_t + G^r_t \tag{5}$$

For instance, when the transfer price (p^r_t) is relatively higher than the market buy price (p^b_t), TD will procure electricity from the market.

➢ Internal transaction (TD → RD)

All of electricity demand in RD ($\bar{y}$) is procured by TD and transmitted to RD at the transfer price (p^r_t), which is defined as a weighted sum between the generation cost (p^w_t) and the market buy price (p^b_t):

$$p^r_t = \beta p^w_t + (1-\beta) p^b_t, \tag{6}$$

where, β is a parameter, which will be explained in the next subsection.

➢ Retail division (RD)

RD sells electricity received from TD to customers adding γ% retail margin, and therefore, the retail price (p^y_t) is

$$p^y_t = (1+\gamma) p^r_t. \tag{7}$$

Obviously, a company can earn more profit if it sets large margin rate. However, actually in the competitive retail market, it is difficult to set a large γ to survive the competition.

3.2. Constraints on vertical integration

In order to compare the VI and MO systems, we assumes two parameters for volume and price constraints on vertical integration.

➢ Volume constraint: α

We postulate that TD has to use electricity from GD, which is generated at the own power plants, to cover at least $\alpha *$ 100% of the retail demand as

$$\sum_i G^r_{it} \geq \alpha \bar{y} \quad (0 \leq \alpha \leq 1). \tag{8}$$

$\alpha = 0$ (MO system): TD can decide the volume to generate at the power plants, to sell to the market, and to buy from the market only based on the market mechanism without any constraints.

$\alpha = 1$ (VI system): TD has to cover all of the retail demand by electricity generated at its own plants in GD regardless of the market price level.

➢ Price constraint: β

As shown in Eq. (6), the internal transfer price (p_t^r) from TD to RD is defined based on the generation cost (p_t^w) and market buy price (p_t^b) weighted by β.

$\beta = 0$ (MO system): The retail price (p_t^y) is defined based on only the market price.

$\beta = 1$ (VI system): The retail price (p_t^y) is defined based on only the generation cost of its own power plants in GD regardless of the market price level.

In this study, we simulate five levels of the constraints as listed in Table 1, respectively.

Table 1: Simulation of constraints on vertical integration

	(MO system) Free ←		Constraint		→ Strict (VI system)
	$a1$	$a2$	$a3$	$a4$	$a5$
$\alpha =$	0	0.25	0.5	0.75	1
	$b1$	$b2$	$b3$	$b4$	$b5$
$\beta =$	0	0.25	0.5	0.75	1

3.3. Profit maximization

Theoretically speaking, GD wants to sell generated electricity at a higher price, while RD wants to procure it at a lower price, which suggests a possibility of internal conflict. TD can resolve it to mediate between the two by aiming at overall profit maximization. Divisional and overall profits are calculated as follows:

➢ Generation division

$$\begin{aligned} &\text{Revenue}: \mathrm{REV}_t^{GD} = p_t^g G_t^e \\ &\text{Cost}: \mathrm{COS}_t^{GD} = \sum_i p_{it}^w G_{it}^e = p_t^w G_t^e \\ &\text{Profit}: \mathrm{PRO}_t^{GD} = (p_t^g - p_t^w) G_t^e \end{aligned} \tag{9}$$

➢ Retail division

$$\begin{aligned} &\text{Revenue}: \mathrm{REV}_t^{RD} = p_t^y \bar{y} \\ &\text{Cost}: \mathrm{COS}_t^{RD} = p_t^r \bar{y} \\ &\text{Profit}: \mathrm{PRO}_t^{RD} = (p_t^y - p_t^r) \bar{y} \end{aligned} \tag{10}$$

➢ Trading division

$$\begin{aligned} &\text{Revenue}: \mathrm{REV}^{TD} = p_t^s \textstyle\sum_i E_{it}^s + p_t^r \bar{y} \\ &\text{Cost}: \mathrm{COS}^{TD} = p_t^g \textstyle\sum_i G_{it}^e + p_t^b E_t^b \\ &\text{Profit}: \mathrm{PRO}^{TD} = p_t^s \textstyle\sum_i E_{it}^s + p_t^r \bar{y} - p_t^g \sum_i G_{it}^e - p_t^b E_t^b \end{aligned} \tag{11}$$

➢ Whole company

$$\begin{aligned} \text{Profit}: \mathrm{PRO}_t &= \mathrm{PRO}_t^{GD} + \mathrm{PRO}_t^{RD} + \mathrm{PRO}_t^{TD} \\ &= p_t^s \textstyle\sum_i E_{it}^s + p_t^y \bar{y} - \sum_i p_{it}^w G_{it}^e - p_t^b E_t^b \\ &= \textstyle\sum_i (p_t^s - p_{it}^w) E_{it}^s + \sum_i (p_t^b - p_{it}^w) G_{it}^r + (p_t^y - p_t^b) \bar{y} \end{aligned} \tag{12}$$

Then, the overall profit maximization model is formulated as

$$\max \ \mathrm{PRO}_t = \textstyle\sum_i (p_t^s - p_{it}^w) E_{it}^s + \sum_i (p_t^b - p_{it}^w) G_{it}^r + (p_t^y - p_t^b) \bar{y}$$

s.t. Eqs. (1), (2), (4), (5), (6), (7) and (8). (13)

In this model, unknown variables are E_{it}^s, G_{it}^r and p_t^y.

3.4. Exogenous variables

In Eq. (13), the fuel and power market prices ($p_{coal,t}^w$, $p_{gas,t}^w$, p_t^s and p_t^b) are exogenous variables, and in this study, we randomly generate the data for T points under the several conditions.

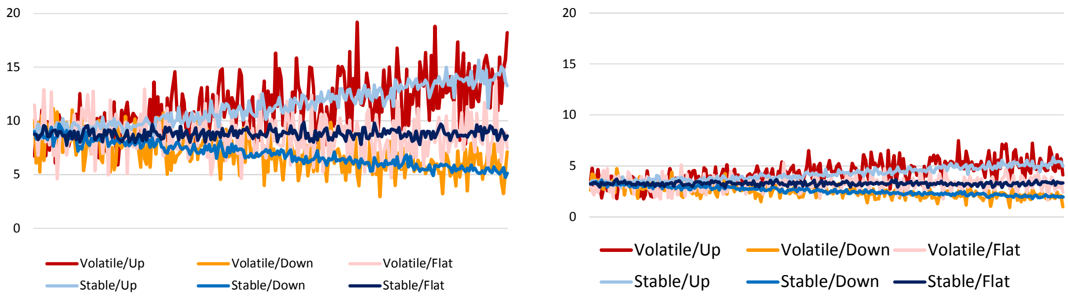
➢ Fluctuation (2 cases)

We assume two different conditions for the market price fluctuation for T periods, i.e. stable and volatile cases.

Average gas and coal prices are defined referring to the actual market prices and converted into the unit of electric energy as ¥8.789/kWh and ¥3.264/kWh, respectively. Average of sell and buy prices in the power market are defined as ¥9.229/kWh, which is 5% higher than the average gas price. The market sell and buy prices are independently generated under the same condition.

[Case 1] Stable: variance of coefficient is 0.05.

[Case 2] Volatile case: variance of coefficient is 0.2.



3a: Gas prices (6 cases)

3b: Coal Prices (6 cases)

Figure 3: Market price setting (for 250 points)

➢ Trend (3 cases)

We assume three conditions for the market price trend for *T* periods, i.e. increase, decrease and flat cases.

[Case1] Up: increasing rate is +0.2%

[Case2] Down: decreasing rate is -0.2%

[Case3] Flat: increasing rate is 0%.

As a result, we generate 6 (=2*3) price series for coal, gas and power prices, respectively, and then we have 216 (=6*6*6) combinations. Figures 3a and 3b show generated data only for gas and coal price series. In addition, combinations of constraints (α, β) are 25 cases, resulting in 5,400 cases in total.

For all of these cases, we solve Eq. (14), respectively, then obtain profit, stability, and competitiveness indices. It should be noted here that, to obtain the stability index, we need to calculate a standard deviation of profits, and therefore, repeated calculation is executed using randomly generated price series (for *T* periods) under the same condition for each case[2]. Then we obtain an average profit, a standard deviation of profits for the stability index, and an average retail price for the competitiveness index for 5,400 cases.

However, in this paper, we fix the coal price series as (Volatile / Flat), because three indices are very similar even if we change the conditions of coal prices. Finally, we use 900 cases for DEA calculation.

[2] In this paper, we show the results of *T*=30.

Furthermore, we postulate three types of fuel mix. Table 2 shows the capacity setting for the power plants in GD by type. Total retail demand ($\bar{y}$) is also exogenous variable, which is defined as 10,000MW, in this study. The retail margin rate γ is defined as 5%, which is typical value in UK power companies.

Table 2: Fuel mix setting

	Gas	Coal	Hydro	Total
Mix 1	8,000	2,000	2,000	12,000
Mix 2	2,000	8,000	2,000	12,000
Mix 3	2,000	2,000	8,000	12,000

3.5. DEA Calculation

As we mentioned, the profit, stability and competitiveness indices for each case may be differently evaluated, e.g. profit is large, while competitiveness is small. In order to obtain the comprehensive evaluation, we apply DEA.

In this study, we use the SBM-max model (Tone, 2015), which refers to the nearest point of the efficiency frontier in the slacks-based model. It can be said that the efficiency score is measured under the best condition for the target DMU.

Profit is regarded as output, while stability (standard deviation of profits) and competitiveness (retail price level) are regarded as input, because they have better evaluation when they are small. DMUs are 900 cases for each fuel mix.

4. RESULTS

4.1. Results of profit maximization

Figures 4a-d plot the results of three indices obtained by Eq. (13) for all three fuel mix cases, and therefore, there are 2,700 (=900*3) dots on each figure. In addition, both inputs (stability and competitiveness indices) are divided by output (profit) in Figure 4d.

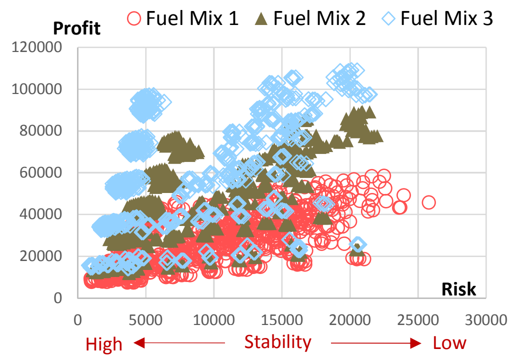
As a fuel price of hydro power is defined as 0, all indices in the fuel mix 3 are better than those in the others, i.e. relatively larger profits, lower risks and lower retail prices, and vice versa for the fuel mix 1, because of strongly dependence on gas power plants.

Figures 5a-d exhibit only for the fuel mix 1, in which GD owns large gas power plant capacity. 900 dots described in this figure are differently colored based on the level of constraints on vertical integration, $a1$ to $a5$ and $b1$ to $b5$. Intuitively, we can find that the blue colored dots ($b1$) are relatively efficient.

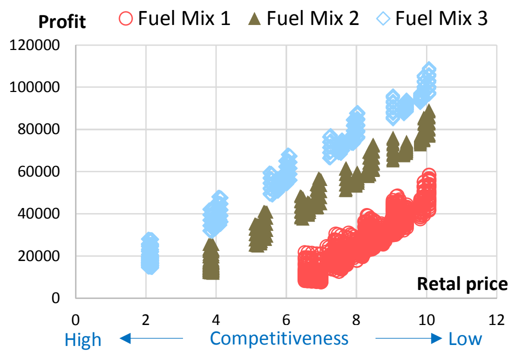
Figures 6a and 6b show the average of three indices in the case of fuel-mix1 by level of constraint. To adjust the level of three indices, every result is divided by total average throughout all constraints.

According to these figures, profits is larger under less constraints, while risk is lower (more stable) under more strict constraints, especially, it is remarkable for the price constraints β. In addition, the volume constraints α have no influence on competitiveness, while strong price constraints β presents higher competitiveness (lower price level).

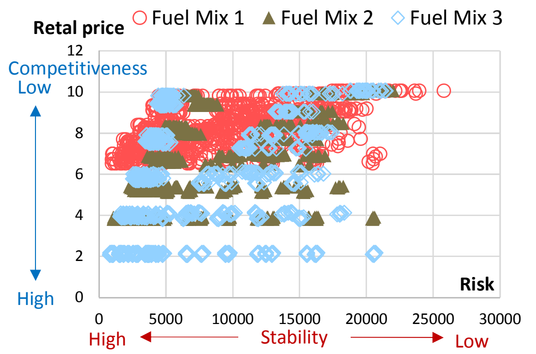
As we assumed, evaluation of these three indices are different for each cases, and therefore, DEA method will help us to comprehensively evaluate them.



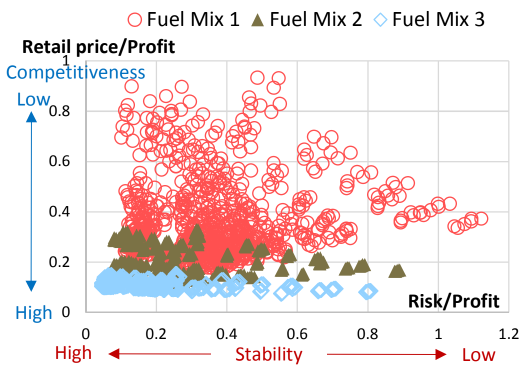
4a: input 1(Risk) v.s. output (Profit)



4b: input 2 (Retail price) v.s. output (Profit)

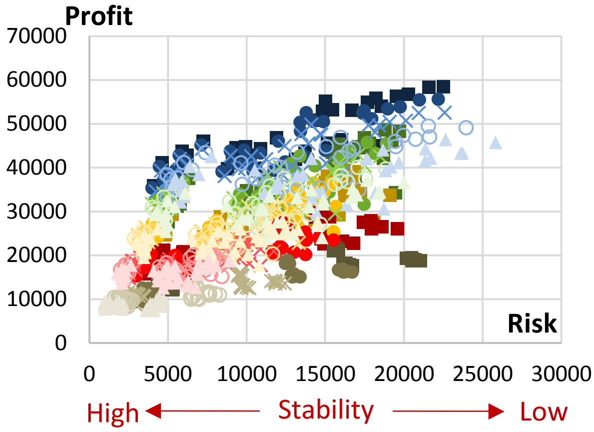


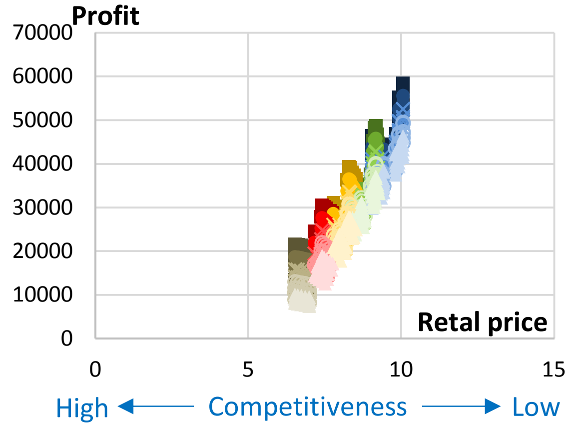
4c: input 1 (Risk) v.s. input 2(Retail price)



4d: input 1/output v.s. input 2/ output

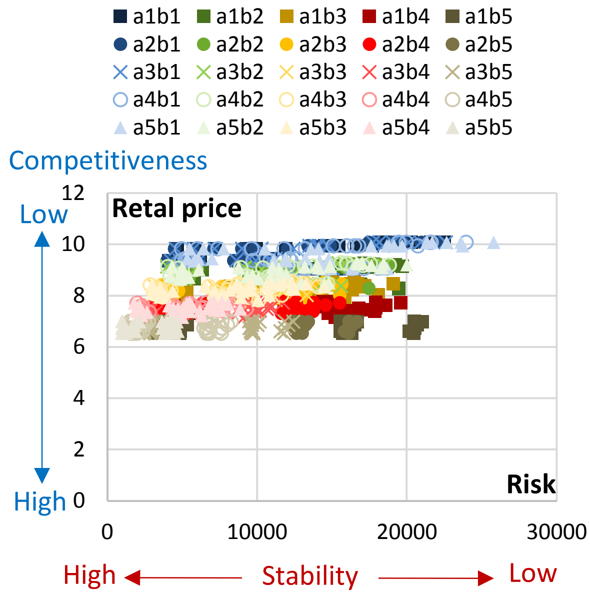
Figure 4: Scatter plot for one output (profit) and two inputs (risk and retail price) for all fuel mix cases

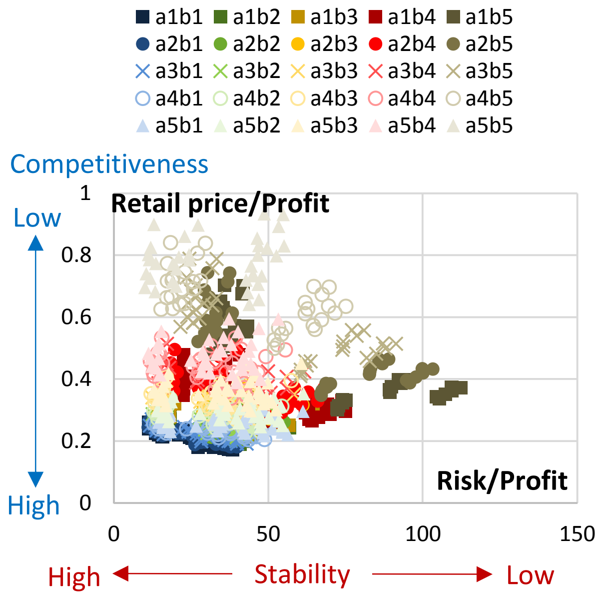




5a: input 1(Risk) v.s. output (Profit)

5b: input 2 (Retail price) v.s. output (Profit)

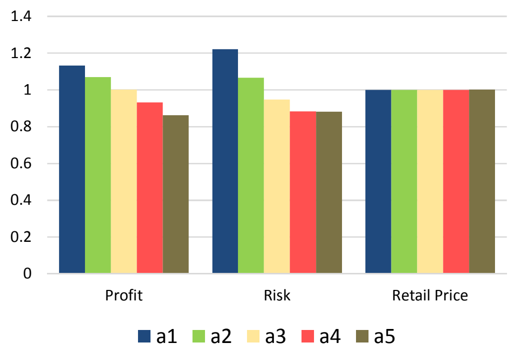


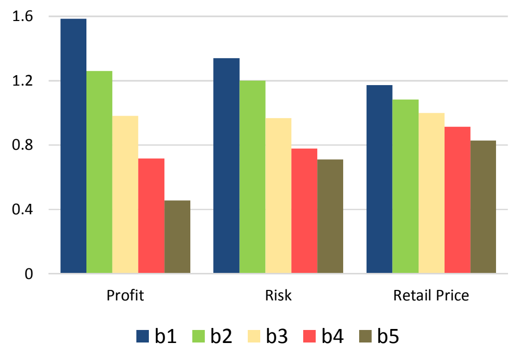


5c: input 1 (Risk) v.s. input 2(Retail price)

5d: input 1/output v.s. input 2/ output

Figure 5: Scatter plot for one output (profit) and two inputs (risk and retail price) for the case of fuel mix 1





6a: average for each volume constraint

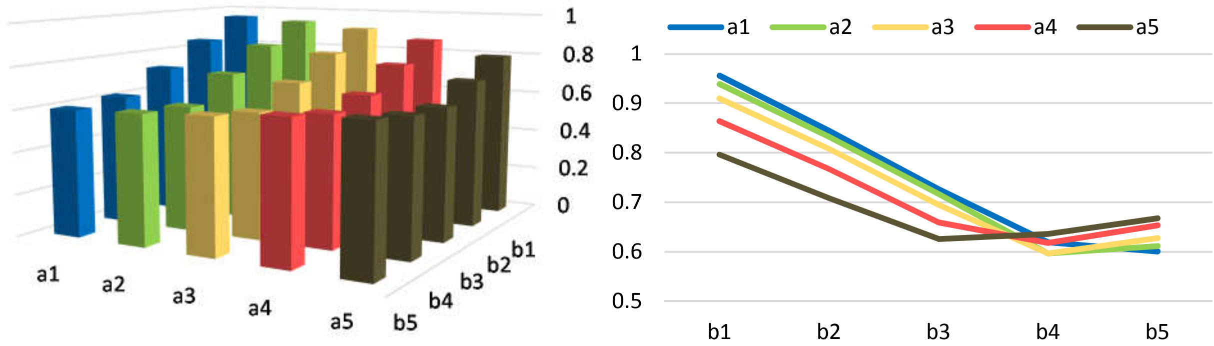
6b: average for each price constraint

Figure 6: Average scores for each constraint for the case of fuel mix 1

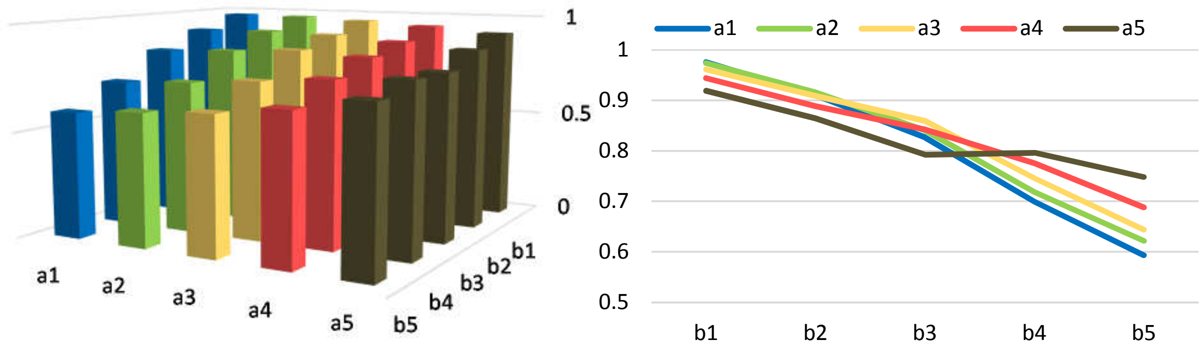
4.2. Result of DEA

Figures 7a-c describe average efficiency scores for each constraint level for each fuel mix. We can find relatively small difference among constraints in the case of fuel mix 3. It is attributable to the inexpensive generation cost in hydro power plants, and therefore, they can generate electricity regardless of the market situation. This implies that trading function will be more effectively workable in a company which own many fossil fueled power plants.

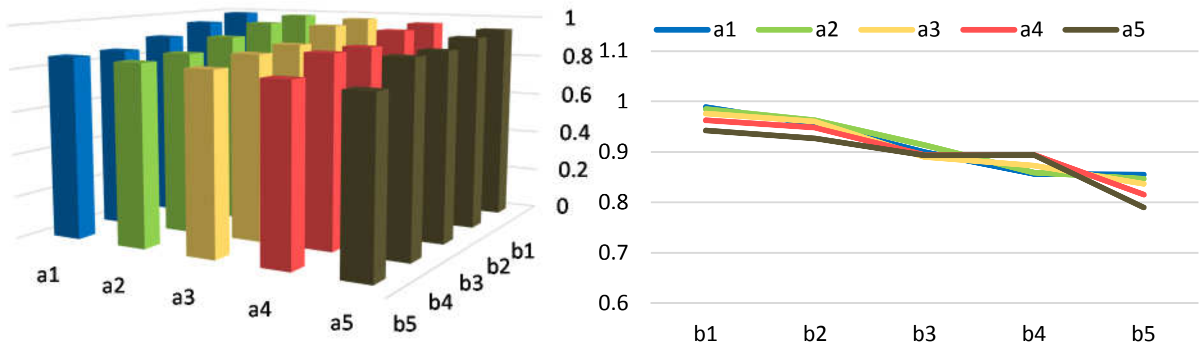
In addition, it can be said that the free constraint case (*a*1 & *b*1), which is just the case of the pure MO system, is most efficient of all, and it becomes less efficient as the constraints become more strict. However, in the most



7a: Fuel mix 1 (The capacity of gas power plant is large)

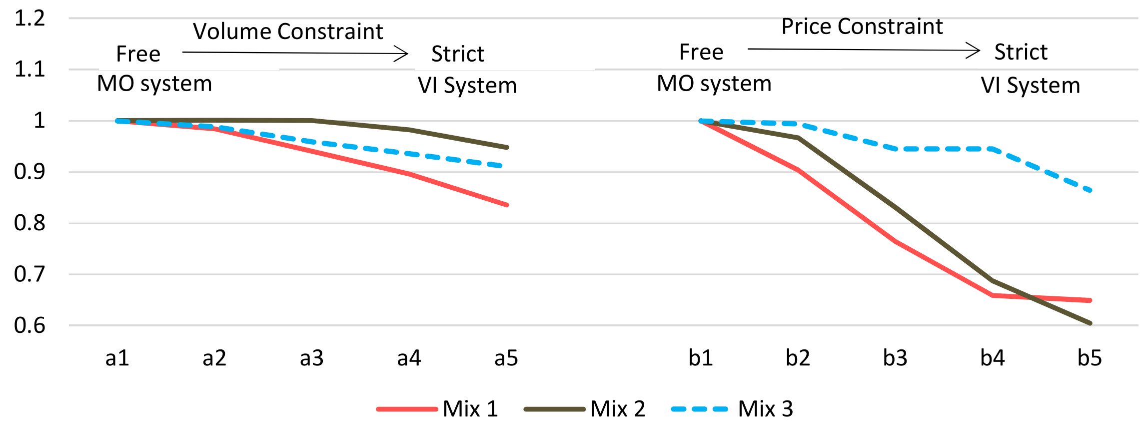


7b: Fuel mix 2 (The capacity of coal power plant is large)

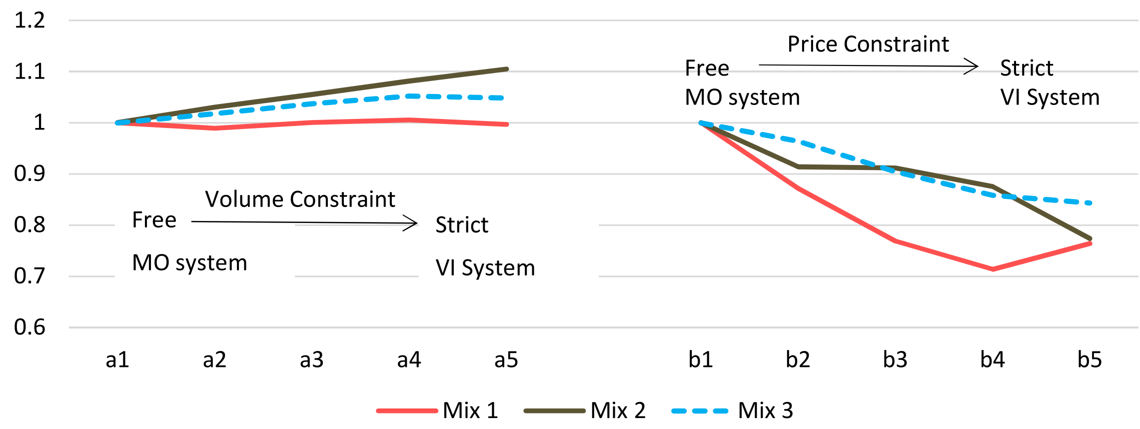


7c: Fuel mix 3 (The capacity of hydro power plant is large)

Figure 7: Average scores for each constraint



8a: Volatile case



8b: Stable case

Figure 8: Efficiency comparison among constrains

strict case (*a*5 & *b*5), which is the case of the pure VI system, the efficiency score can be better than that of the several other cases in the cases of fuel mix 1 and 2.

Figures 8a and 8b focus on cases of volatile and stable in the power market price, in which scores are divided by the scores under no constraint case (*a*1 or *b*1) in order to compare the difference among constraints in all fuel mixes. In the volatile case, the MO system with less constraints performs better under every fuel mix. Therefore, if a company predicts power price in the market will volatile in the future, the MO system will be suitable for it, especially, for the company owning large gas power plants.

5. CONCLUDING REMARKS

In this study, we artificially generated price data for T periods, but they are finally averaged to only one value. Therefore, in the future work, we would like to calculate moving averages to evaluate the change of time series. Furthermore, we will examine several different settings to obtain more robust results.

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