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Restructuring and Reliability in the Electricity Industry of OECD Countries: Investigating Causal Relations between Market Reform and Power Supply †

Hanee Ryu [1,*], Yeonbae Kim [2], Pilseong Jang [3] and Sergio Aldana [4]

1 Hyundai Research Institute, Seoul 03127, Korea
2 Technology Management, Economics, and Policy Program, Seoul National University, Seoul 08826, Korea; kimy1234@snu.ac.kr
3 Science and Technology Policy Institute, Sejong 30147, Korea; psjang@stepi.re.kr
4 Instituto Nacional de Electrificación, Ciudad de Guatemala 01009, Guatemala; sdam9@hotmail.com
* Correspondence: hanee.ryu@gmail.com; Tel.: +82-10-7706-5685
† This paper is based on dissertation research completed at Seoul National University by Hanee Ryu for Ph.D. degree.

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Abstract: Power supply security tops the agenda of policies, and it is related to restructuring with the intention of improving efficiency. To investigate relationships between restructuring and reliability in the electricity industry of 15 OECD countries from 1987 to 2013, reliability is measured by the index of the sub-sectors (resources, generation, transmission and distribution, and electricity import), and the effects of the forms of liberalized restructuring—entry, privatization, and vertical divestiture—on sub-sectors are evaluated with the random-effect model. Results indicate that restructuring has a partially negative relationship with reliability, but the effect differs by the type of liberalization and supply sub-sectors.

Keywords: reliability; power supply; restructuring; market reform; random-effect model

1. Introduction

Supply reliability reflects the ability to meet demand and safeguard supply in an electricity system [1]. As energy security becomes a trending issue, the discussion of reliable electricity supplies and essential energy sources has also expanded. Because it is a life-sustaining energy source and an essential prerequisite in utilizing goods and services, electricity tops the agendas of policymakers worldwide, and reliable supply is considered a core objective in the utility industry [2]. Serious consequences, including damage to national economies from disruptions in the supply of essential energy sources, were witnessed in the California power crisis of 2001 and the blackout of 2003 in the northeast of the U.S. As a result, efficiency and low price are not the only an important issues related to the electricity supply; the electricity industry must address reliability of supply as well.

Concerned voices have been raised about electricity industry restructuring (i.e., liberalization) designed to improve supply efficiency, but which may deteriorate electricity supply reliability [3,4]. That is, trade-offs between efficiency and reliability of supply characterize the electricity industry. An empirical analysis on the relationship between restructuring and satisfying steady supply of electricity is needed to address industry trade-offs. In this paper, we used an econometric model to evaluate empirically the supply reliability in four separate sub-sectors of the electricity industry.

Supply reliability is realized when electricity continuously meets timely demands and disruption in supply is avoided. An interruption in energy supply might occur at any level of the supply chain;

therefore, electricity supply reliability should be evaluated at multiple places in the value chain [1]. For this paper, we divided the electricity supply system, which ranges from acquisition of resources for electricity generation to delivery of energy to customers, into four sub-sectors according to its supply chain: resources, generation, transmission and distribution (T&D), and electricity import. Supply reliability for each sub-sector is measured with the following variables (sub-sector): resource import dependency (resources), reserve factor (generation), disturbance time in T&D (T&D), and electricity import dependency (electricity import). Data from 1987 to 2013 of 15 Organisation of Economic Co-operation and Development (OECD) countries were used to measure restructuring in three dimensions: entry liberalization, privatization, and vertical divestiture.

Although a few studies have addressed electricity supply reliability in the face of industry restructuring, to our knowledge, we present the first empirical study to consider possible dimensions of restructuring and supply reliability. Some previous empirical studies include those from [5] and [6]. However, [6] only focused on the effect of "ownership unbundling (vertical divestiture)" on T&D investment and reliability. [5] analyzed impacts of liberalization on overall investments in the electricity industry. Of course, the investment variable is closely related to supply reliability; however, as a variable, it is limited in the ability to provide consistent measures. For example, a decrease in investment does not mean a negative effect on the industry because previous investment may come from excess funding. In contrast, the reserve factor as a means to determine generation or disturbance time in T&D directly and consistently measures supply reliabilities.

The paper is organized as follows: Section 2 represents theoretical backgrounds on the relationship between restructuring and supply reliability in the electricity industry. Section 3 explains the econometric model used to investigate the causal relationships between restructuring and reliability. Section 4 shows the results of the regression. Section 5 wraps up this paper with conclusions and recommendations.

2. Literature Review—Studies on Restructuring and Supply Reliability

Some previous literature pointed out disincentives to invest in securing the generation capacity required to meet power demands in a competitive electricity market. In most competitive electricity markets, wholesale prices do not rise high enough to reflect the value of lost load and clear the market. As a result, low prices may lead to underinvestment in generation capacity [4,7,8]. Several reasons for investment shortfalls in competitive markets are addressed in previous studies: price-insensitive consumers; social costs caused by network collapse or voltage reductions that are not reflected in market prices; price caps, far below the value of lost load, for electricity imposed by regulators to deal with potential market power problems; and pressure to impose marginal cost pricing in a competitive market [7,8]. Furthermore, underinvestment may be caused by the high risk of lumpy investments in electricity generation, which result from price variability experienced after entry liberalization [9].

U.S. power systems have shown decreasing reserve margins due to underinvestment after entry liberalization and price deregulation [4,7,9]. Forward capacity obligations and associated auction mechanisms that determine capacity prices (i.e., capacity payments) are suggested to restore appropriate wholesale market prices and associated investment incentives in the competitive electricity market [4,7,8].

In conclusion, some previous arguments point to the potential negative impacts of entry liberalization on supply reliability. However, because some countries in the competitive market have used mechanisms (such as forward capacity obligations and capacity payments) to make up for the negative impacts [4,7,8], we cannot reach a conclusion without an empirical analysis to reveal evidence of the effects of restructuring the electricity industry.

Recently, ref. [5] showed empirical results for a similar issue: entry liberalization increases investment in the electricity industry. However, they did not address the effect of liberalization, which may be associated with investment shortfalls that lead to failure to meet increasing demand.

The literature on transaction cost economies and economies of vertical integration provides some rationale for the vertical structure of an electricity value chain [10]. Considering transaction cost theories, we expect to find a potential mismatch in operation and investment (i.e., a coordination problem) between vertically separated firms. The investment and operation contract between separate firms on the vertical value chain will be costly when new investment in one stage requires adjustment in preceding or subsequent stages to realize the potential value of the investment [10,11]. Transaction costs increase with increasing relationship-specific investments [6,12]; therefore, the coordination of investment plans is particularly useful in an power supply system in which the technology of the generation sub-sector has a close relationship with that used in the T&D sub-sector (i.e., economies of coordination are used) [6,13]. Ref. [3] claimed that vertical divestiture reduces investment because firms have poor incentives to invest in networks to gain additional profit. Ref. [5] emphasized that the electricity industry depends on coordination because demand must equal supply at each point in time, and coordination between infrastructure investments and generation assets may fail if the decision-making entities operate differently from each other or if the market is not regulated.

Ref. [5] empirically showed that vertical divestiture decreases the investment toward generating capacity and T&D networks for 16 European countries from 1998 to 2008. Ref. [14] presented the first empirical study to examine the impact of unbundling on T&D supply reliability (network quality) by focusing on 14 Union of the Coordination of the Transmission of Electricity (UCTE) countries between 2001 and 2010. The study showed that network reliability decreases due to delivery delays related to the network disturbance caused by vertical divestiture.

Other previous studies regarding unbundling and incentives to invest deserve recognition for their role in understanding the electricity industry. Contrary to those pointing to the negative effects of vertical divestiture, some economists suggested that vertical divestiture of the transmission network and interconnections presents a structural solution to the problem of low investments in the grid that subsequently results in a high concentration of markets that favor incumbents [9]. There is the lack of incentive for vertically integrated generators to invest in T&D capacity [15,16]. Vertically integrated utility companies may recognize that the substitution and strategic effects due to increased T&D capacity would limit their market power in the wholesale electricity markets, and, thus, they may strategically underinvest [6].

The theoretical argument on the effects of privatization on investment applies to supply reliability and underinvestment. The ownership structure of firms in the electricity sector may affect investments in two areas: efficiency and incentive or objective effects [5]. If public ownership is related to X-inefficiency, state-controlled energy sectors should receive lower investments than other sectors; however, according to [5], if state-controlled firms have different objectives from private firms, such as the buildup of a good and secure infrastructure for electricity, then the state-controlled firms may invest more than privately controlled firms focused on short-run performance as informed by the tough monitoring of the capital market, stock market myopia, and take-over threats. Based on their empirical estimates for European electricity markets, they showed that public ownership is detrimental to investment.

The security problem may also affect resources sectors of the electricity industry. Loss of welfare may result because of price fluctuations, sudden price hikes, or supply interruptions of fossil fuels in international markets, which are caused by resource market concentration and political instability of the resource exporting countries [16–18]. In this paper, we chose to use import dependency to measure supply reliability in the resources sector. High resource import dependency increases the risk of supply disruption because price risk and physical availability cannot be controlled [17].

To our knowledge, no previous theoretical or empirical study has been undertaken on the restructuring of the electricity industry and resource import dependency. However, from previous arguments on energy security, we investigate a possible theoretical linkage between restructuring and resource import dependency. Because of the big gap between social and private benefits from enhanced security (externality of the security), long-term and centralized regulation of the industry must be undertaken by the government. Specifically, because decentralized power and private ownership maximize short-run profits during electricity restructuring, security may suffer such that responsible governance is required [19].

Of course, electricity imports alleviate some of the energy supply reliability problem, and limited electricity import dependency can be considered as flexible way to improve response to demand changes in an internationally integrated electricity market. Although flexible electricity imports may improve supply reliability, excessive import dependency can create supply disruptions, as well as price increases and fluctuations caused by external factors. In summary, effects of electricity imports on supply reliability differ by the amount of electricity imported.

In theory, we look at two opposing perspectives. First, new entrants inspired by regulatory reforms, such as through entry liberalization, may have incentives to rely on electricity imports from foreign countries and are not compelled to build up new generating capacity. Second, firms separated by vertical divestiture may prefer to contract with domestic firms than face the higher transaction costs required to deal with foreign suppliers. Such a choice results in decreased electricity imports after restructuring and diminishes the flexibility associated with foreign energy as a supplemental source of electricity.

3. Econometric Model

3.1. Main Variables

Before assessing the effect of restructuring of the power sector on supply reliability, we must first understand the nature of supply reliability and regulatory reforms. To make this assessment for each of the sub-sectors of electricity supply structures (resources, generation, T&D, electricity import), an indicator suitable for quantitatively evaluating supply reliability was selected and measured. Resource import dependency, reserve factor, disturbance time in T&D, and electricity import are used as independent valuables for representing the level of supply reliability in the sub-sectors of resources, generation, T&D, and imports, respectively.

Indicators for quantitatively evaluating electricity industry restructuring were also selected. Electricity industry restructuring is measured in various dimensions—entry liberalization, privatization, and vertical divestiture—as each is used to assess restructuring issues. Despite a few studies that explained the theory of industry restructuring and supply reliability, this is the first empirical study to consider all possible dimensions of regulatory reforms and energy security.

3.1.1. Reliability Variables for Sub-Sectors

For each sub-sector of electricity supply structures—from acquiring resources for power generation to delivery of energy to customers—impediments in supply reliability may differ. According to the peculiarities of each sub-sector, we selected a quantitative index that embraces the uniqueness of each. We divided the process into the sub-sectors of resources, generation, T&D, and electricity import.

Resources

Failure in supply reliability indicates the degree of possible interruption in energy supply, and in the resources sub-sector, it suggests inability to procure resources. Such failure is due to a price spike following a sudden price fluctuation or physical unavailability of resources [17]. In this paper, we show the level of import dependency in resource procurement as the measurement of possible disruption in resource supply. Equation (1) was used to compute the resource import dependency that is used to evaluate supply reliability in the resources sub-sector. It shows the share of net imports of each fossil fuel f in the total primary fossil-fuel energy supply of a particular country i in year t. The equation shows the primary energy supply of each fossil fuel (coal, oil, and natural gas) for a whole country and thus reflects the nation-wide resource procurement circumstance.

$$Resource\ Import\ Dependency_{it} = \frac{\sum_f Net\ Import_f}{Total\ Primary\ Fossil - Fuel\ Energy\ Supply} \tag{1}$$

Coal includes hard, brown, and other subordinate (Hard coal includes anthracite as well as coking, bituminous, and sub-bituminous coals. Brown coal includes lignite in Australia, Finland, France, and Portugal. In Canada, Germany, Hungary, Italy, the Netherlands, Norway, Spain, and the United Kingdom, brown coal includes sub-bituminous specimen.) types. Oil includes crude oil, natural gas liquid, and feedstock. Natural gas includes total import via pipeline and liquefied, natural gas. Data for OECD countries were computed using IEA databases [20–24] offers the main data sources up to 2011, and updated data to 2013 were as indicated from the annual published reports from 2014 and later). The index for each fossil fuel was calculated only for net importers. Net exporters' import dependency for a resource is denoted by 0.

Generation

Supply reliability should include a measure for generation capacity that accommodates fluctuating demand. For the generation sub-sector, we choose reserve factor, which exhibits available operational capacity in the time of peak demand. It shows supply surplus level by the capacity to handle sudden increases in peak demand [1]. This measure discerns a risk of possible power outages by generation supply deficit created by underinvestment [1].

$$Reserve\ Factor_{it} = \frac{Maximum\ Available\ Capacity}{Peak\ Demand} \tag{2}$$

Maximum available capacity for the reserve factor calculation, as shown in Equation (2), depends not only on the capacity investment level but also on the technology state of the equipment and operational capacity. It may be less than net maximum capacity due to unanticipated shutdowns, lack of water for hydro operations, and other factors [21]. Peak demand is the highest simultaneous demand for electricity satisfied in country *i* during the year *t* [21]. All available datasets for the reserve factor came from the IEA database [20–24].

Transmission and Distribution

Supply reliability in the T&D sub-sector can be measured by the frequency and lengths of disruptions that arise in a transmission and distribution system. In this paper, we used disturbance time to measure the supply reliability in the T&D sub-sector; this term refers to the minutes in country *i* during the year *t* in which electricity in unavailable in a network. It is standardized through measures of the T&D distance (km).

$$Disturbance\ Time_{it} = \frac{Time\ of\ Unavailability\ of\ Network\ for\ Unplanned\ Disturbances\ (Min.)}{Grid\ Length\ (Megameter)} \tag{3}$$

Reasons for the disturbance times include overloads or failure in the T&D network as well as overloads, false operation, or failure of protection devices or other elements [25]. Quantifying unexpected disruption of an energy supply into an index can be accomplished by using the most representative, direct measures of supply reliability experienced by customers (This study investigates the possibility of restructuring undermining the reliability of supply in each subsystem. That is, we explored the possibility that some form of disturbance occurring in each subsystem, although the actual supply disturbance does not take place. In this study, we distinguished the T&D network from other networks and used the unplanned disturbance time as a specified variable for this network.

We would like to note, however, "disturbance time" is the result of the undermined reliability of supply that occurs in resources and generation, in respect to the stages of electricity supply that manifests itself as the supply disturbance in the T&D network. In order to identify the effects of restructuring on actual supply disturbance, it is necessary to investigate how the reliability of supply is undermined in resource and generation stages prior to the T&D network, and further clarify their interconnectedness). Data for unplanned disturbances time (minutes) and grid length (megameter) are based on the ENTSO-E Statistical Yearbook [25–36].

Electricity Import

Electricity import provide a source of energy during a time of supply unreliability. Specifically, they are used when power plants within the national boundary do not produce energy and so the electricity is imported and delivered to end-users. Supplementing domestic supply with low levels of electricity import is considered a flexible way to improve response to demand in an internationally integrated electricity market [1]. On one hand, the flexible role of limited electricity imports is expected to improve supply reliability as it diversifies the national response to meet domestic demands. On the other hand, excessive import dependency can cause supply disruption or price increase and fluctuation through external factors. In summary, effects of electricity imports on energy security differ according to the proportion of demand met by foreign suppliers.

Equation (4) was used to calculate electricity import dependency (the ratio of the amount of electricity imports in the total consumption of country i and year t). Data for electricity import came from IEA databases.

$$Electricity\ Import_{it} = \frac{Electricity\ Import(KWh)}{Total\ Electricity\ Consumption(KWh)} \quad (4)$$

3.1.2. Indicators for Restructuring

Electricity industry restructuring was measured via three aspects of regulatory reform: entry liberalization, privatization, and vertical divestiture. A restructuring index from the OECD International Regulation Database [37] was used to analyze types and progressions of regulatory reforms of the electricity industry. The degree of regulation in entry liberalization, a form of business ownership, and the degree of vertical divestiture in power generation as well as T&D were quantitatively measured and then computed as the weighted average of their sub-level indicators [37].

First, the entry liberalization indices were created based on three sub-level indicators: regulation on third party access (TPA), existence of liberalized wholesale market, and minimum consumption threshold for free choice of the supplier [37]. Each sub-indicator carries the same weight, and the higher value is assigned, from 0 to 6, if the entry to market is more liberalized. For example, if TPA is mandatory (regulated TPA), a liberalized wholesale market is established, and no threshold is required to account for free choice of the supplier; then, each sub-indicator has a value of 6, which indicates the most liberalized market entry.

Second, a form of business ownership was measured by the percentage of shares owned by the government in the largest corporations conducting business in generation/import, transmission, distribution, and supply segments of the electricity industry. The more privatized the firm, the higher value assigned (from 0 to 6) to it.

Third, the vertical structure of the electricity industry was measured by the level of vertical separation between a specific segment (generation/import, transmission, distribution, and supply segments of the electricity industry) and other segments of the electricity sector: The values range from 0 (integrated) to 6 (separated). A detailed description of the restructuring indicators is found in Appendix A.

3.2. Estimation Model

To quantify relationships between electricity supply reliability in each sub-sector and degree of restructuring, we designed an econometric model. For each sub-sector, indicators of restructuring were assigned as important explanatory variables, and supply reliability indicators were assigned as dependent variables in the regression analysis. The inferring causal effect of restructuring on the resources sub-sector is shown in Equation (5), the generation sub-sector is presented in Equation (6), the T&D sub-sector in found in Equation (7), and the electricity import sub-sector is illustrated in Equation (8).

$$\begin{aligned} &\mathit{Resource\ Import\ Dependency}_{it} \\ &\quad = \gamma_0 + \gamma_1 \mathit{Entry\ Liberalization}_{it} + \gamma_2\ \mathit{Privatization}_{it} \\ &\quad +\gamma_3 \mathit{Vertical\ Divestiture}_{it} + \gamma_4 \mathit{Eletricity\ Consumption}_{it} \\ &\quad +\gamma_5 \mathit{Population}_{it} + \gamma_6 \mathit{GDP}_{it} \end{aligned} \tag{5}$$

$$\begin{aligned} &\mathit{Reserve\ Factor}_{it} \\ &\quad = \delta_0 + \delta_1 \mathit{Entry\ Liberalization}_{it} + \delta_2\ \mathit{Privatization}_{it} \\ &\quad +\delta_3 \mathit{Vertical\ Divestiture}_{it} + \delta_4 \mathit{Eletricity\ Consumption}_{it} \\ &\quad +\delta_5 \mathit{Population}_{it} + \delta_6 \mathit{GDP}_{it} \end{aligned} \tag{6}$$

$$\begin{aligned} &\mathit{Disturbance\ Time}_{it} \\ &\quad = \eta_0 + \eta_1 \mathit{Entry\ Liberalization}_{it} + \eta_2\ \mathit{Privatization}_{it} \\ &\quad +\eta_3 \mathit{Vertical\ Divestiture}_{it} + \eta_4 \mathit{Eletricity\ Consumption}_{it} \\ &\quad +\eta_5 \mathit{Population}_{it} + \eta_6 \mathit{GDP}_{it} \end{aligned} \tag{7}$$

$$\begin{aligned} &\mathit{Electricity\ Import\ Dependency}_{it} \\ &\quad = \theta_0 + \theta_1 \mathit{Entry\ Liberalization}_{it} + \theta_2\ \mathit{Privatization}_{it} \\ &\quad +\theta_3 \mathit{Vertical\ Divestiture}_{it} + \theta_4 \mathit{Eletricity\ Consumption}_{it} \\ &\quad +\theta_5 \mathit{Population}_{it} + \theta_6 \mathit{GDP}_{it} \end{aligned} \tag{8}$$

To control each nation's characteristic electricity production and consumption scales, levels of electricity consumption (electricity production), population (electricity demand), and GDP (electricity demand) were set as control variables in each equation. The control variable datasets came from the open-access World Bank database. GDPs are deflated at 2005 constant price (in USD) using the GDP deflators that were published by World Bank. We expect that supply reliability will be illustrated by shortfalls experienced as the electricity production and demand scales of a country increase because large-scale industries tend to reflect many risks that must be controlled from both production and demand sides.

There might be a further suggestion on how some variables included in the regression equation could be relevant in the introduction of renewable energy sources. For purposes of this paper, nonetheless, the period we investigated did not yield significant results in respect to the impact of renewable energy sources on relevant variables, due to insufficient introduction of renewable energy sources. In the future, however, when the supply of renewable energy sources rises significantly and the integration of the electricity market is further along, and also due to the intermittence of the renewable energy sources, the electricity exports may increase. In this case, the impact of the introduction of renewable energy on relevant variables may be observed, and the effects of restructuring may be different.

3.3. Sample Data

We used panel data from 15 OECD countries obtained from 1987 to 2013. The data coverage depended on the availability of regulatory reform data. Because the data are available only from 2002 for UTCE member countries, inputs for data for the T&D sub-sector were collected for eight European countries from 2002, and three countries were added to the database after 2009. Hence, unbalanced panel data were used for this research. Summarized descriptions and descriptive statistics for the dataset are shown in Table 1. Information from select countries and the mean values of the main variables by nation are shown in Appendix B.

According to the correlations shown in Appendix C, control variables representing national scales of production and consumption were high. However, most of the explanatory variables were associated with a low correlation value.

Table 1. Descriptive statistics.

Sub-Sectors	Variables	Description	Data Source	Mean (s.d.)	Min.	Max.
Resources	Resource Import Dependency	Range from 0 to 1, net exporter's import dependency is marked with '0'	IEA database [20–24]	0.5 −0.32	0	0.99
Generation	Reserve Factor	Available operational capacity in the time of peak demand	IEA database [20–24]	1.19 −0.18	0.74	1.75
T&D	Disturbance Time	Duration of unplanned disturbance (Min/Mm), standardized with T&D distance	UTCE, RGCE, ENTSO-E [25–36]	0.01 −0.03	0	0.25
Electricity Import	Electricity Import Dependency	Range from 0 to 1	IEA database [20–24]	0.08 −0.08	0	0.42
Restructuring Variables	Entry Liberalization	Range from 0 to 6 with weighted average of low-level indicators	OECD Sector PMR indicators [38]	3.38 −2.74	0	6
	Privatization	Range from 0 to 6 with weighted average of low-level indicators		2.344 −2.24	0	6
	Vertical Divestiture	Range from 0 to 6 with weighted average of low-level indicators		0.91 −0.84	0	3.56
Control Variables	Electricity Consumption	Total amount of electricity consumption (TWh)	World bank database [39]	496.08 −872.35	20.64	4154.97
	GDP	Gross domestic production based on USD 2005 (trillion) constant prices		1.82 −2.73	0.07	14.45
	Population	Million persons		54.36 −69.26	4.19	316.13

4. Results and Discussion

4.1. Estimation Method

Random- and fixed-effect models for panel data analysis were used to estimate Equations (5)–(8) [40]. Because the resource import dependency and electricity import (dependent variables), which include net export per country, are censored at zero, a Tobit model is the appropriate choice to handle this problem [40]. Ref. [41] suggested a way to estimate a fixed-effect panel Tobit model in which the estimator shows consistency. The Hausman test was performed on each equation to test the validity of choosing either a random-effect or a fixed-effect model. In this analysis, a random-effect model was chosen for all equations over fixed-effect models that did not lead to rejection of the null hypothesis: differences in coefficients showed no systematic pattern. For each equation, the null hypothesis states that a covariance matrix that is diagonal (zero covariance between equations) is not rejected. The following values from the χ^2 distribution in the Hausman tests indicate an accepted null hypothesis: 1.66 (for resource import dependency), 2.06 (for reserve factor), 5.87 (for disturbance time), and 0.55 (for electricity import). This finding means that the particular explanatory variables (restructuring) are not correlated with nation-specific effects.

4.2. Effect of Restructuring on Sub-Sector Reliability

Model 1, shown in Table 2, provides the estimation result of Equation (5), which we used to analyze the relationship between supply reliability and restructuring in the resources sub-sector. The coefficient for privatization on resource import dependency is positive (0.013) at 1% statistical significance; however, the other restructuring variables do not exhibit significant relationships with resource import dependency. This finding implies that the business ownership with more privatization elements experiences greater resource import dependency. When the maximum value of privatization was multiplied by 6, the coefficient (0.014) indicated that resource import dependency increased from 8% to 58% from the mean value (50%) of the data. Because greater resource import dependency entails an impediment in supply reliability due to greater risk of interruption or price hike, restructuring in the form of privatization exerts a negative effect on continuous reliable supply. The finding comports with conclusions by Palm (2008): policy objectives that advocate for national energy supply security in the resources sub-sector may not match the agenda of individual privatized firms.

Table 2. Restructuring and reliability (random-effect model).

	Dependent Variables			
	Model 1 (Tobit)	**Model 2**	**Model 3**	**Model 4 (Tobit)**
Explanatory Variables	**Resource Import Dependency**	**Reserve Factor**	**Disturbance Time**	**Electricity Import**
Entry liberalization	0.0004 (0.002)	−0.028 *** (0.008)	−0.007 (0.006)	0.012 *** (0.002)
Privatization	0.013 *** (0.003)	0.025 * (0.014)	0.002 (0.002)	−0.001 (0.002)
Vertical divestiture	−0.008 (0.007)	−0.063 ** (0.027)	−0.008 (0.008)	−0.013 ** (0.006)
Electricity consumption	−0.0003 *** (0.00009)	−0.000001 (0.0003)	0.00008 (0.0001)	0.00007 (0.00007)
Population	−0.003 (0.002)	−0.013 *** (0.005)	0.001 (0.001)	−0.0005 (0.001)
GDP	0.127 *** (0.019)	0.361 *** (0.128)	−0.032 (0.021)	−0.024 ** (0.012)
Constant	0.470 *** (0.067)	1.357 *** (0.053)	0.047 (0.034)	0.070 ** (0.036)
No. of observation	385	191	101	385
Wald chi-sq, *p*-value	0.00	0.00	0.05	0.00

The standard errors are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Model 2 shows the estimation result of Equation (6), which was used to investigate the relationship between supply reliability and restructuring in the generation sub-sector. It shows a negative and significant coefficient value (−0.028) on entry liberalization at a 1% significance level and (−0.063) on vertical divestiture at a 5% significance level, but a positive significant coefficient value (0.025) at the 10% level when the reserve factor is the dependent variable. Our findings show that a decrease in reserve factor indicates a reduced ability to respond in times of peak demand and a heightened possibility of disruption in electricity supply. The coefficient value means that the maximum value (6) of entry liberalization is associated with a reserve factor decrease of approximately 0.17 from the value obtained when the least liberalized market degree is measured (at minimum value of 0). The decreased value (1.02) can indicate a serious interruption if the mean value (1.19) of the reserve factor drops as entry liberalization is completed. Although it is almost offset by the maximum privatization level (6), vertical divestiture (maximum value of 3.56) also hinders the supply margin as it is decreased by 0.22. The closer the reserve factor to 1, the higher the possibility of supply interruptions. Hence, the result affirms the notion that restructuring in the form of liberalized entry and vertical divestiture have a detrimental effect on supply reliability [5,8,9].

Model 3 was used to determine the casual relation between restructuring and supply reliability in the T&D sector. One might expect normalized disturbance time to relate with ownership unbundling, but it is not supported by the findings, which show no statistically significant values.

Model 4 shows the regression result of Equation (8), which we used to evaluate the relationship between restructuring and supply reliability in terms of electricity import dependency and. Both entry liberalization and vertical divestiture have a statistically significant (at 1% and 5% levels) coefficient value (0.012 and −0.013), but their effects have opposite signs. Entry liberalization exhibits a positive causal relation with electricity import dependency. With a maximum value (6) of entry liberalization, the coefficient is associated with an electricity import share increase of 15%, which can be interpreted as improving demand response. Normally limited electricity imports enhance the supply flexibility, but the outcome depends on the level of electricity market integration. In addition, we found a negative relationship between vertical divestiture and electricity import dependency. The vertical divestiture was associated with a decrease in electricity imports of 3.40%—from a mean value of 8% of electricity import share—as calculated with a maximum value (3.56) of vertical divestiture.

4.3. Causal Relationship between Restructuring and Reliability

As entry liberalization has a negative causal relationship with the reserve factor, the result attests that an increase in competition as part of restructuring negatively affects the steady supply of electricity. However, our findings indicate an increase in shares of electricity import; hence, an increase in flexibility of energy supply shows a positive effect on reliability. Entry liberalization that aims to promote competition could induce lowered reserve factor, as incumbents are incentivized to increase operating rate of existing capacity rather than to invest in capacity building. In the aspect of electricity imports, entry liberalization could also allow entrants to gain access to market without capacity building, increasing the electricity imported in the process.

The restructuring that shifts business ownership into a more privatized one increases dependency on resource imports, but it improves reliability in the generation sector by increasing the reserve margin. However, privatization results in decentralized power that may require that government hold firms accountable for producing reliable electricity [19]. Meanwhile, government intervention to improve X-inefficiency of public ownership may result in adverse outcomes in the generation sub-sector [5].

The vertical divestiture shows negative causality with the reserve factor and electricity import. It results from the failure of the internalization of vertical externality and coordination. Vertically integrated firms often cannot meet the demand and hesitate to invest in new capacity until future demand is made clear. Furthermore, to avoid transaction costs, separated firms may not import electricity from foreign firms.

Restructuring exerts differing effects by type. According to the result of this research, restructuring, which is designed for improving efficiency, is associated with some partly adverse outcomes, especially on domestic electricity supply reliability.

5. Conclusions and Policy Implications

When the ownership structure changes through privatization, the incongruence of objectives between the firms governed by the state and those owned by individual businesses causes a negative effect on the reliability of supply sectors such that government oversight may be required. Privatization accompanying a change in operational objectives implies that pursuit of profit by an individual enterprise may interfere with the goal of a stable national electricity supply system. Certain objectives, such as managing the import dependency level, which is usually beyond the scope of businesses, cannot be guaranteed by voluntary efforts of enterprises and requires a public policy approach. Therefore, an integrated managerial system must be devised at the national level to assure steady operation of a system for energy supply after privatization.

Restructuring, which allows entrance of new enterprises and subsequently changes the existing competitive ecosystem, may cause underinvestment in capacity. This, in turn, undermines supply reliability. The short-term goal of maximizing profit through achievement of a higher operation ratio in existing capacity may result in underinvestment in capital and damage the reliability of the energy supply in the long term. Creation of an incentive system is necessary to resolve issues of underinvestment in generation capacity as the result of increasing competition.

Discussions on the generation sub-sector must involve the ways by which an increased reserve factor can help attain supply reliability without countering efficiency. That is, an increase in reserve factor may lower the operation ratio of capacity and therefore can negatively affect efficiency levels.

As the degree of efficiency varies based on the reserve margin of a particular country and organization of power plants, it also depends on an agreed-upon level of reserve factor, thereby reflecting unique national characteristics. Aside from the direct discussion on efficiency, this research attests to the negative effect of restructuring on supply reliability due to an increase in the operation ratio created by a pursuit of efficiency in the short term, the problem of underinvestment in the long term, and subsequent adverse effect of reduction in reserve factors on the reliability of supply.

The effect on electricity imports differs depending on the types of restructuring. A new entrant could increase the electricity import share of the nation, which could increase the new firm's chance to enter the market without investing in capacity for generation. However, a firm separated through vertical divestiture could decide to contract a domestic firm and thus reduce transaction costs and decrease electricity imports. Such action by a divested firm could hurt the nation by avoiding the imports that can improve demand response ability.

Approximately 20% of electricity import share could play an important role in improving the ability to respond to demand. Therefore, entry liberalization has a positive effect and vertical divestiture has a negative effect on supply reliability. However, an excessive dependency on imports increases the possibility of disruption in supply; therefore, future research on the effect of imported electricity on supply reliability and the extent to which imported electricity has a positive impact on supply reliability is required. As electricity trade among nations becomes more prevalent and market integration is increasingly undertaken, the need for investigation in the role of imported electricity will be continuously required.

Because the various types of restructuring exert an inconsistent effect, their impact on electricity supply sectors varies. One must be aware that restructuring with a particular objective may not engender an expected outcome, and the final outcome may yield an unwanted result. Hence, a more comprehensive understanding on net effect is required.

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Appendix A. Regulatory Reform Index

The OECD International Regulation Database provides indicators that are useful for measuring regulatory restrictions in energy, transportation, and communication. The indicators cover T&D and supply in the electricity industry. They include the following low-level measures in the electricity industry: barriers to entry, public ownership, and vertical integration.

The indicators for entry regulation focus on terms and conditions for third party access (TPA) and the extent that consumers may choose their suppliers. Regulated TPA, free consumer choice, and a liberalized wholesale power market presumably promote competition. The indicator for public ownership records the prevailing ownership structure, which ranges from fully private to fully public. The indicators for vertical integration reflect the status of electricity generation and supply compared to natural monopoly activities. The degree of separation ranges from full integration to legal and accounting separation to separation into different companies owned by different shareholders. The assumption, reflecting industrial organization theory, is that the scope for anticompetitive behavior is largest when an electricity or gas company simultaneously controls the network and operates in upstream or downstream competitive markets [14].

We use three kinds of liberalization indices: entry liberalization, privatization, and vertical separation based on the weighted averages of the sub components of each category. The value of them ranges from 0 to 6 and corresponds with the degree of liberalization from least to greatest. The specific contents and weights are given in Table A1.

Table A1. Indicators for liberalization in the electricity industry.

<table>
<tr><th>Liberalization Measures</th><th>Questions</th><th>Weights</th><th colspan="6">Liberalization Degree</th></tr>
<tr><td rowspan="6">Entry Regulation</td><td rowspan="2">How are the terms and conditions of third party access (TPA) to the electricity transmission grid determined?</td><td rowspan="2">1/3</td><td colspan="2">Regulated TPA</td><td colspan="2">Negotiated TPA</td><td colspan="2">No TPA</td></tr>
<tr><td colspan="2">6</td><td colspan="2">3</td><td colspan="2">0</td></tr>
<tr><td rowspan="2">Is there a liberalized wholesale market for electricity?</td><td rowspan="2">1/3</td><td colspan="3">yes</td><td colspan="3">No</td></tr>
<tr><td colspan="3">6</td><td colspan="3">0</td></tr>
<tr><td rowspan="2">What is the minimum consumption threshold that consumers must exceed to be able to choose their electricity supplier? (Gigawatts)</td><td rowspan="2">1/3</td><td>No Threshold</td><td><250</td><td>250–500</td><td>500–1000</td><td>>1000</td><td>No Consumer Choice</td></tr>
<tr><td>6</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td>Privatization</td><td>Where the percentage of shares except owned, either directly or indirectly, by the government in the largest firm in sector?</td><td>1</td><td colspan="6">% of shares not owned by public sector/100 × 6</td></tr>
<tr><td rowspan="2">Vertical Separation</td><td rowspan="2">What is the degree of vertical separation between a certain segment of the electricity sector and other segments of the industry?</td><td rowspan="2">1</td><td colspan="2">Ownership Separation</td><td>Legal Separation</td><td>Accounting Separation</td><td colspan="2">No Separation</td></tr>
<tr><td colspan="2">6</td><td>4.5</td><td>3</td><td colspan="2">0</td></tr>
</table>

Appendix B. Mean Values of Descriptive Variables

Table A2. Mean values of main variables.

Country	Resource Import Dependency	Reserve Factor	Disturbance Time	Electricity Import	Entry Liberalization	Privatization	Vertical Divestiture
Australia	0.06	1.28	-	0.00	3.94	0.17	0.50
Canada	0.00	1.22	-	0.03	2.81	0.00	0.89
Finland	0.55	1.06	0.002	0.15	4.12	1.81	1.36
France	0.49	1.08	0.020	0.02	2.94	0.24	0.60
Germany	0.52	1.31	0.024	0.07	3.11	4.78	0.63
Greece	0.81	1.20	0.013	0.07	2.43	1.30	0.75
Hungary	0.53	1.31	0.003	0.27	2.53	2.06	1.01
Italy	0.85	1.14	0.013	0.15	2.80	1.81	1.04
Japan	0.82	1.11	-	0	3.05	5.78	0.31
Netherlands	0.90	1.38	0.000	0.16	3.28	0.89	0.83
Norway	0.02	1.14	0.000	0.05	5.11	1.50	0.90
Portugal	0.80	-	0.004	0.13	3.20	2.41	1.57
Spain	0.74	1.03	0.022	0.03	3.53	3.73	1.39
United Kingdom	0.15	-	0.015	0.04	5.12	4.55	0.94
United States	0.33	-	-	0.01	2.68	4.57	0.86

Appendix C. Correlation

Table A3. Correlation between variables.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1)	1.00									
(2)	0.13	1.00								
(3)	0.17	−0.19	1.00							
(4)	0.01	0.29	−0.27	1.00						
(5)	−0.06	−0.04	−0.05	−0.04	1.00					
(6)	0.44	−0.23	0.39	−0.13	0.04	1.00				
(7)	0.23	−0.35	0.09	−0.13	0.23	0.75	1.00			
(8)	0.35	−0.06	0.24	−0.46	0.22	0.55	0.59	1.00		
(9)	0.54	−0.00	0.28	−0.31	0.14	0.68	0.61	0.95	1.00	
(10)	0.49	−0.05	0.22	−0.38	0.20	0.52	0.54	0.98	0.97	1.00

Note: (1) Resource import dependency, (2) reserve factor, (3) disturbance time, (4) electricity import, (5) entry liberalization, (6) privatization, (7) vertical divestiture, (8) electricity consumption, (9) population, (10) gross domestic product.

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