RIETI Discussion Paper Series 07-E-023

Oligopolistic Competition in the Japanese Wholesale Electricity Market: A Linear Complementarity Approach

TANAKA Makoto
RIETI

Research Institute of Economy, Trade & Industry, IAA
The Research Institute of Economy, Trade and Industry
http://www.rieti.go.jp/en/

RIETI Discussion Paper Series 07-E -023

Oligopolistic Competition in the Japanese Wholesale Electricity Market: A Linear Complementarity Approach*

Makoto Tanaka **

National Graduate Institute for Policy Studies (GRIPS)
Research Institute of Economy, Trade and Industry (RIETI)

March 2007

Abstract

Using a linear complementarity approach, we simulate the Japanese wholesale electricity market as a transmission-constrained Cournot market. Following Hobbs (2001), our model adopts the Cournot assumption in the energy market and the Bertrand assumption in the transmission market. The Bertrand assumption means that generators consider transmission charges as being exogenous, which can be interpreted as a kind of bounded rationality. We then present a simulation analysis of the Japanese wholesale electricity market, considering eight areas linked by interconnection transmission lines. Specifically, this paper examines the potential effects of both investment in interconnection transmission lines and the divestiture of dominant players' power plants.

JEL classification numbers: L13, L94
Keywords: electricity, wholesale, transmission, Cournot, complementarity

* I am grateful to Tatsuo Hatta, Yoshitsugu Kanemoto, Hasuike Katsuhito, and Koji Takenaka for their helpful comments. I would also like to thank seminar participants at the National Graduate Institute for Policy Studies (GRIPS), the Research Institute of Economy, Trade and Industry (RIETI), and the annual meeting of the Japanese Economic Association. The usual disclaimers apply.
** National Graduate Institute for Policy Studies (GRIPS), 7-22-1 Roppongi, Minato-ku, Tokyo 106-8677, Japan. E-mail: mtanaka@grips.ac.jp.

1. Introduction

Due to advances in mathematical modeling capabilities, simulation models of Cournot competition in electricity markets are gaining increasing attention. Such simulation models are being applied to the electricity markets in some countries to support policy decisions on market design, market monitoring, and other regulatory tasks.

However, there have been few simulation analyses of Cournot competition in the Japanese electricity market. Akiyama and Hosoe (2006) conduct a simulation of perfect competition in the Japanese electricity market. Hattori (2003) examines Cournot competition in the Western region of Japan, while Hasuike and Kanemoto (2005) investigate Cournot competition in the Eastern region of Japan. However, Hattori, and Hasuike and Kanemoto do not consider transmission constraints explicitly in their models.

One of the challenges in Cournot modeling of electricity markets has been the inclusion of transmission constraints. Hobbs and Helman (2004) argue that there are two approaches to modeling Cournot generators on transmission networks. One approach is to assume that generators can manipulate transmission charges. The other approach is to assume that generators cannot consciously manipulate transmission charges.

Cardel et al. (1997), Borenstein and Bushnell (1999), Borenstein et al. (2000), and Hobbs et al. (2000) examine the former approach in detail. Tanaka (2006) applies this approach to evaluation of the Japanese electricity market. In these models, sophisticated generators can correctly predict the effects of their decisions on transmission charges. These models are formulated as equilibrium problems with equilibrium constraints (EPEC). The disadvantage of this approach is that each generator’s maximization problem is highly nonconvex and difficult to solve. There may be no equilibrium or multiple equilibria.

The latter approach is examined by Smeers and Jing-Yuan (1997), Hobbs (2001), and Metzler et al. (2003). In these models, generators are naive with respect to how their generation choices will affect transmission congestion and charges. In other words, this approach adopts the Bertrand assumption in the transmission market. The Bertrand assumption means that generators consider transmission charges as being exogenous, which can be interpreted as a kind of bounded rationality. The advantage of this approach is that we can formulate mixed complementarity problems (MCP) that have a unique solution.

In this paper, we adopt the latter approach, following Hobbs (2001): that is, the

Cournot assumption in the energy market and the Bertrand assumption in the transmission market. Using a linear complementarity approach, we then simulate the Japanese wholesale electricity market, considering eight areas linked by interconnection transmission lines. Specifically, this paper examines the potential effects of both investment in interconnection transmission lines and the divestiture of dominant players' power plants.

The remainder of the paper is organized as follows. In Section 2, we present a model of a transmission-constrained Cournot market. In Section 3, we present the simulation results of the Japanese wholesale electricity market. Section 4 summarizes our results.

2. The Model

2.1 DC Network Model

We consider an electric power network with nodes $n = 1,\dots,N$ and transmission lines $l = 1,\dots,L$. The transmission capacity of each line is denoted by the vector $\mathbf{k} \equiv (k^1,\dots,k^L)'$.[1] Let $q^{n,d}$ and $q^{n,s}$ denote the power demand and the power generation at node n, respectively. $Q^n(q^{n,s}, q^{n,d}) \equiv q^{n,s} - q^{n,d}$ represents the net injection at node n.

We consider the DC load flow approximation (see, for example, Schweppe et al., 1988 for details), focusing on the network where transmission losses are small and negligible. The power flow on transmission line l, $F^l(\mathbf{q})$, can be expressed as a linear function of the net injection $Q^n(q^{n,s}, q^{n,d})$:

$$F^l(\mathbf{q}) \equiv \sum_n h^{l,n}\, Q^n(q^{n,s}, q^{n,d}), \qquad (1)$$

where $h^{l,n}$ is the power transfer distribution factor, or PTDF.[2]

$B^n(q^{n,d})$ denotes the gross benefit of electricity consumption at node n, and $P^n(q^{n,d})$ denotes the marginal benefit (or inverse demand function) at node n. Note that $\partial B^n(q^{n,d}) / \partial q^{n,d} = P^n(q^{n,d})$. Moreover, $C^n(q^{n,s})$ and $MC^n(q^{n,s})$ denote the total and marginal cost of power generation at node n, respectively.

---

[1] A bold symbol represents a vector or a matrix. $\mathbf{a}'$ denotes the transpose of $\mathbf{a}$.

[2] As is customary in the electric power engineering literature, $h^{l,n}$ represents the increase in the power flow on line l resulting from a unit increase in the power transferred from node n to the swing bus.

2.2 Cournot Generators

Following Hobbs (2001), we adopt the Cournot assumption in the energy market and the Bertrand assumption in the transmission market. In other words, generators have market power in the energy market, but cannot consciously manipulate congestion and transmission charges. The Bertrand assumption means that generators consider transmission charges as being exogenous, which can be interpreted as a kind of bounded rationality.

Let w^n denote the withdrawal charge at node n. Generators pay the system operator a withdrawal charge w^n to withdraw power at node n. In contrast, generators get w^n (pay $-w^n$) when they inject power at node n. Note that one has to pay the system operator $-w^n + w^m$ in order to transmit power from node n to node m (i.e., inject power at node n and withdraw it at node m). Thus, $-w^n + w^m$ can be seen as the transmission charge (or wheeling charge). We assume that w^n is exogenous for generators.

Since the total power generated is equal to the total amount demanded, $\sum_i q^{i,s} = q^{n,d} + \sum_{j \neq n} q^{j,d}$ holds. The RHS of the equation is the total amount demanded, which is decomposed into the power demand at node n and the power demand at other nodes. Thus, the power demand at node n can be written as $q^{n,d} = \sum_i q^{i,s} - \sum_{j \neq n} q^{j,d}$. Moreover, the wholesale energy price (or nodal price) at node n can be expressed as $P^n(q^{n,d}) = P^n(\sum_i q^{i,s} - \sum_{j \neq n} q^{j,d})$.

For notational simplicity, we here assume that there is one Cournot generator at each node. Then, the profit maximization problem of Cournot generator n can be stated as follows:

$$\max_{q^{n,s}} P^n(\sum_i q^{i,s} - \sum_{j \neq n} q^{j,d}) q^{n,s} - C^n(q^{n,s}) \qquad (2)$$

$$\text{s.t. } P^n(\sum_i q^{i,s} - \sum_{j \neq n} q^{j,d}) - w^n = P^m(\sum_i q^{i,s} - \sum_{j \neq m} q^{j,d}) - w^m, \quad \forall m \neq n \qquad (3)$$

$$q^{n,s} \geq 0 \qquad (4)$$

Equation (3) can be rewritten as $P^m - P^n = -w^n + w^m$. In other words, the energy price difference between any two nodes is exactly equal to the transmission charge between them; that is, there are no arbitrage opportunities.

2.3 System Operator

An efficient power market is characterized by the maximization of the social welfare subject to the energy balance and transmission capacity constraints. Since the total power generated during any given hour has to be equal to the total amount demanded, the energy balance constraint can be written as $\sum_n Q^n(q^{n,s}, q^{n,d}) = 0$. Moreover, the transmission capacity constraint can be expressed as $|F^l(\mathbf{q})| \le k^l$, because the power flow on each line cannot exceed the line's capacity. Note that we take the absolute value of $F^l(\mathbf{q})$ considering the direction of the power flow.

The system operator solves the following maximization problem:

$$\max_{\mathbf{q}^d} \sum_n \left\{ B^n(q^{n,d}) - C^n(q^{n,s}) \right\} \qquad (5)$$

$$\text{s.t.} \quad \sum_n Q^n(q^{n,s}, q^{n,d}) = 0, \qquad (6)$$

$$\sum_n h^{l,n} Q^n(q^{n,s}, q^{n,d}) \le k^l, \quad \forall l, \qquad (7)$$

$$-\sum_n h^{l,n} Q^n(q^{n,s}, q^{n,d}) \le k^l, \quad \forall l, \qquad (8)$$

$$\mathbf{q}^d \ge 0. \qquad (9)$$

Let λ be the shadow price associated with the energy balance constraint. Let $\eta^{l+}, \eta^{l-} \ge 0$ be the shadow prices associated with the transmission capacity constraints. Considering those nodes at which $q^{n,d} > 0$, the Karush-Kuhn-Tucker (KKT) conditions with respect to $q^{n,d}$ yield the standard nodal pricing formulas:

$$P^n(q^{n,d}) = \lambda + \sum_l h^{l,n} \left(\eta^{l-} - \eta^{l+} \right). \qquad (10)$$

λ is usually called the system price, which is a uniform energy price over all nodes.

Based on the standard nodal pricing method, the withdrawal charge at node n can be defined as the difference between the nodal price at node n and the system price;

that is, $w^n \equiv P^n(q^{n,d}) - \lambda = \sum_l h^{l,n}\left(\eta^{l-} - \eta^{l+}\right)$. Note that w^n depends on the degree of congestion in the network, and hence η^{l+}, η^{l-}.

2.4 Solution Approach

We assume that the inverse demand functions and marginal cost functions are linear. Moreover, note that the power flow equations can be expressed as linear functions of the net injection, as mentioned in subsection 2.1. Thus, the KKT conditions for the generators' and system operator's maximization problems define a mixed linear complementarity problem (LCP).[3] This mixed LCP can be solved numerically using solvers such as PATH and MILES.

3. Simulation Analysis

3.1 Simulation Setup

We analyze the Japanese electricity market of eight incumbent electric power companies. Figure 1 shows the market areas of the incumbent firms and the interconnection transmission lines between the areas. We consider each area as a node in the network.[4] The supply capability and peak load for fiscal year 2001 are summarized in Table 1.[5] The capacity of each interconnection transmission line is shown in Table 2.

[Insert Figure 1 about here]

[Insert Table 1 about here]

[Insert Table 2 about here]

Our analysis focuses on the peak period. We estimate linear demand and marginal cost functions using publicly available data for fiscal year 2001. Following Hasuike

[3] We can formulate a mixed LCP, in which the number of conditions equals the number of variables, by rearranging the conditions and eliminating redundant conditions.

[4] The system operation within each area is not considered in our simulation.

[5] The supply capability includes the power output of relatively small electric utilities other than the eight incumbent electric power companies; for example, hydroelectric power generated by municipal electric utilities and Electric Power Development Co., Ltd., and nuclear power generated by Japan Atomic Power Co., Ltd. We consider the power plants of these electric utilities as must-run plants in our simulation.

and Kanemoto (2005), we set the price elasticity of demand and the reference price at 0.1 and 10 yen/kWh, respectively, for all areas. The load is set at the maximum three-day average peak load in each area. Then, a linear demand function is calibrated for each area. We next estimate a linear marginal cost function for each incumbent electric power company, using power plant data such as the amount of fuel burned, the fuel consumption rate, and fuel prices. The basic parameters are summarized in Table 3.

[Insert Table 3 about here]

About 35% of all electricity demand, mainly household consumption, is still regulated in Japan. We consider regulated demand as an exogenous variable in our simulation. Note also that throughout this paper we focus on the short-term welfare and do not discuss the issue of fixed cost.

3.2 Base Case: Cournot Competition among Eight Incumbent Generators

We perform a simulation of Cournot competition among the eight incumbent generators, which we refer to as the base case. Figure 2 summarizes the results of this base case simulation. The transmission capacity of the interconnection line between area B and area C, namely line 2, is very limited. Under Cournot competition, line 2 is heavily congested from area C to area B, which divides the market into the Eastern and Western regions. This results in a significant price difference between the two regions: the energy prices are 19.23 yen/kWh and 12.80 yen/kWh in the Eastern and Western regions, respectively.

[Insert Figure 2 about here]

Figure 3 compares the energy prices under Cournot competition with those under perfect competition. The congestion on Line 2 is much less severe under perfect competition than under Cournot competition. Indeed, the price difference between the two regions is very small under perfect competition: the energy prices are 7.46 yen/kWh and 7.31 yen/kWh in the Eastern and Western regions, respectively.

[Insert Figure 3 about here]

Figure 4 compares the quantities generated under Cournot competition with those under perfect competition. Under Cournot competition, the quantities produced in areas B, C, and E are decreased, while those produced in the other five areas are increased.

[Insert Figure 4 about here]

The welfare comparisons are reported in Table 4. Under Cournot competition, consumer surplus decreases by 880 million yen/h, while producer surplus increases by 793 million yen/h; congestion revenue increases by 8 million yen/h; and social surplus decreases by 80 million yen/h, which is the welfare (deadweight) loss in the Cournot market.

[Insert Table 4 about here]

3.3 Effects of Upgrading Transmission Capacity

We analyze the effects of upgrading the bottleneck transmission line, namely line 2. Figure 5 shows the price changes due to the upgrading of line 2's capacity up to 7,200MW. The price difference between the two regions becomes smaller as the capacity of line 2 increases: the energy price in the Eastern region falls, while that in the Western region rises. However, note that the capacity of the interconnection line between area C and area E, namely line 3, becomes congested when line 2's capacity reaches to about 3,600MW.

[Insert Figure 5 about here]

Table 5 reports the welfare changes due to the upgrading of line 2's capacity. Consumer surplus rises and producer surplus falls as the capacity of line 2 increases. By upgrading line 2's capacity to 7,200MW, social surplus increases by 11 million yen/h as compared to that in the base case. Note that we focus on the short-term welfare, and the issue of capacity cost is not discussed here.

[Insert Table 5 about here]

Figures 6, 7, and 8 summarize the results of upgrading the capacity on line 2 to 2,400MW, 4,800MW, and 7,200MW, respectively.

[Insert Figure 6 about here]

[Insert Figure 7 about here]

[Insert Figure 8 about here]

3.4 Effects of Divestiture

We examine the effects of the divestiture of generating plants by incumbent electric power companies. Five hypothetical divestiture scenarios are discussed:

Scenario I: firm B is split into two companies.

Scenario II: firm B is split into three companies.

Scenario III: firm B is split into four companies.

Scenario IV: firms A, B, C, and E are respectively split into two companies.

Scenario V: firm B is split into six companies; firms A, C, and E are each split into two companies.

As illustrated in Figure 9, the divestiture of firm B, the largest generator, has the significant effect of mitigating market power. The energy price in the Eastern region falls from 19.23 yen/kWh to 14.45 yen/kWh in Scenario I, since the Eastern region becomes more competitive. Moreover, the energy price in the Eastern region falls to 12.79 yen/kWh in Scenario II, in which case the congestion on line 2 is relieved and the price difference between the two regions disappears. In Scenario III, the direction of the power flow on line 2 reverses due to increasing competition in the Eastern region. The welfare results are reported in Table 6. In comparison with the base case, the increases in consumer surplus are 208, 286, and 338 million yen/h in Scenarios I, II, and III, respectively. The increases in social surplus are 39, 49, and 52 million yen/h in Scenarios I, II, and III, respectively.

[Insert Figure 9 about here]

[Insert Table 6 about here]

In Scenarios IV and V, we further consider the divestiture of firms A, C, and E. Particularly in Scenario V, the energy prices in both regions fall to 10.96 yen/kWh due to increasing competition in the two regions. Note that the congestion on line 2 is relieved and the price difference between the two regions disappears as in Scenario II.

As compared to the base case, the increases in consumer surplus are 327 and 518 million yen/h in Scenarios IV and V, respectively. The increases in social surplus are 51 and 68 million yen/h in Scenarios IV and V, respectively.

The results of divestiture Scenarios I to V are summarized in figures 10 to 14, respectively.

[Insert Figure 10 about here]

[Insert Figure 11 about here]

[Insert Figure 12 about here]

[Insert Figure 13 about here]

[Insert Figure 14 about here]

4. Concluding Remarks

Following Hobbs (2001), we have adopted the Cournot assumption in the energy market and the Bertrand assumption in the transmission market, in which generators consider transmission charges as being exogenous. By using a linear complementarity approach, we have then simulated the Japanese wholesale electricity market, considering eight areas linked by interconnection transmission lines. Specifically, this paper has examined the potential effects of both investment in interconnection transmission lines and the divestiture of dominant players’ power plants.

Under Cournot competition among the eight incumbent generators, the interconnection line between area B and area C, namely line 2, is heavily congested from area C to area B, which divides the market into the Eastern and Western regions. This results in a significant price difference between the two regions: the energy prices are 19.23 yen/kWh and 12.80 yen/kWh in the Eastern and Western regions, respectively.

We have next analyzed the effects of upgrading the bottleneck transmission line, namely line 2. The price difference between the two regions becomes smaller as the capacity of line 2 increases: the energy price in the Eastern region falls, while that in the Western region rises. However, the capacity of the interconnection line between area C and area E, namely line 3, becomes congested when line 2’s capacity reaches about 3,600MW.

We have then examined the effects of the divestiture of generating plants by incumbent electric power companies. The energy price in the Eastern region falls from 19.23 yen/kWh to 14.45 yen/kWh in Scenario I (firm B is split into two companies), since the Eastern region becomes more competitive. Moreover, the energy price in the Eastern region falls to 12.79 yen/kWh in Scenario II (firm B is split into three companies), in which case the congestion on line 2 is relieved and the price difference between the two regions disappears. In Scenario III (firm B is split into four companies), the direction of the power flow on line 2 reverses due to increasing competition in the Eastern region. The divestiture of firm B, the largest generator, has the significant effect of mitigating market power.

In this work, we have considered an electric power network where transmission losses are small and negligible. Further work should aim to incorporate transmission losses into the model. With regard to the transmission constraints, we have focused on the thermal limit of each line. Further work is needed to incorporate other realistic constraints such as limits on voltage and stability. Another avenue for future research is to extend the framework to incorporate forward markets.

References

Akiyama, S., and N. Hosoe (2006) "A Spatial Equilibrium Analysis of Transmission Charge Reform in Japan's Electric Power Industry," RIETI Discussion Paper Series 06-E-022.

Borenstein, S., and J. B. Bushnell (1999) "An Empirical Analysis of the Potential for Market Power in California's Electricity Market," *Journal of Industrial Economics* 47, 285-323.

Borenstein, S., J. B. Bushnell, and S. Stoft (2000) "The Competitive Effects of Transmission Capacity in a Deregulated Electricity Industry," *Rand Journal of Economics* 31(2), 294-325.

Cardell, J. B., C. C. Hitt, and W. W. Hogan (1997) "Market Power and Strategic Interaction in Electricity Networks," *Resource and Energy Economics* 19, 109-137.

Federation of Electric Power Companies of Japan, FEPC (2002) *Handbook of Electric Power Industry* (in Japanese).

Hasuike, K., and Y. Kanemoto (2005) "Policy Evaluation for Oligopolistic Markets–A Case of Wholesale Electricity Market," RIETI Discussion Paper Series 05-J-024 (in Japanese).

Hattori, T. (2003) “A Simulation Analysis of the Potential for Market Power in the Western Segment of the Prospective Japanese Electricity Market,” Paper presented at Advanced Workshop in Regulation and Competition, 16th Annual Western Conference, San Diego, California.

Hobbs, B. F. (2001) “Linear Complementarity Models of Nash-Cournot Competition in Bilateral and POOLCO Power Markets,” *IEEE Transactions on Power Systems* 16, 194-202.

Hobbs, B.F. and U. Helman (2004) “Complementarity-Based Equilibrium Modeling for Electric Power Markets,” in D.W. Bunn (eds.) *Modeling Prices in Competitive Electricity Markets*. London, U.K.: J. Wiley.

Hobbs, B. F., C. B. Metzler, and J.-S. Pang (2000) “Strategic Gaming Analysis for Electric Power Systems: An MPEC Approach,” *IEEE Transactions on Power Systems* 15, 637-645.

Metzler, C. B., B. F. Hobbs, and J.-S. Pang (2003) “Nash-Cournot Equilibria in Power Markets on a Linearized DC Network with Arbitrage: Formulations and Properties,” *Networks and Spatial Economics* 3(2), 123-150.

Ministry of Economy, Trade and Industry, METI (2002) 7th Meeting of Electricity Industry Committee, reference document (in Japanese).

Ministry of Economy, Trade and Industry, METI (2003) *Outlook for Electric Supply and Demand* (in Japanese).

Schweppe, F. C., M. C. Caramanis, R. D. Tabors, and R. E. Bohn (1988) *Spot Pricing of Electricity*. Norwell, MA: Kluwer Academic Publishers.

Smeers, Y., and W. Jing-Yuan (1997) “Spatially Oligopolistic Model with Opportunity Cost Pricing for Transmission Capacity Reservations—A Variational Inequality Approach,” Universite’ Catholique de Louvain, CORE Discussion Paper 9717.

Tanaka, M. (2006) “A Simulation Analysis of Transmission-Constrained Oligopoly in the Wholesale Electricity Market,” RIETI Discussion Paper Series 06-J-010 (in Japanese).

Table 1. Supply Capability and Peak Load (2001)

Unit: MW

	A	B	C	D	E	F	G	H	Total
Supply capability	17,383	62,375	31,194	6,794	33,163	13,383	7,203	20,792	192,287
Peak load	13,480	61,431	26,246	5,021	30,901	10,840	5,449	15,971	169,339

Note: The supply capability includes the power output of relatively small electric utilities such as municipal electric utilities. Peak load represents the maximum three-day average peak load.

Source: Estimated from METI (2003), FEPC (2002), and others.

Table 2. Capacity of Interconnection Transmission Line

Unit: MW

	1 (A-B)	2 (B-C)	3 (C-E)	4 (E-D)	5 (E-F)	6 (F-G)	7 (F-H)
Transmission capacity	6,000	1,200	5,570	5,570	16,660	2,400	5,570

Source: METI (2002).

Table 3. Basic Parameters

	A	B	C	D	E	F	G	H
Slope of demand function	-0.007418	-0.001628	-0.003810	-0.019916	-0.003236	-0.009225	-0.018352	-0.006261
Slope of marginal cost function	0.0005038	0.0001374	0.0002881	0.0013662	0.0002971	0.0006538	0.0010837	0.0005339

Table 4. Comparison of Cournot and Perfect Competition: Welfare

Unit: 1,000 yen/h

	Cournot competiton	Perfect competition
Consumer surplus	7,881,240	8,761,543
Producer surplus	1,657,938	864,748
Congestion revenue	7,711	176
Social surplus	9,546,889	9,626,467

Table 5. Welfare Changes Due to Upgrading of Transmission Capacity on Line 2

Unit: 1,000 yen/h

	Base case	2,400MW	3,600MW	4,800MW	6,000MW	7,200MW
Consumer surplus	7,881,240	7,887,836	7,895,392	7,905,887	7,916,805	7,928,164
Producer surplus	1,657,938	1,648,621	1,639,515	1,628,259	1,619,205	1,612,334
Congestion revenue	7,711	13,363	17,541	20,995	21,035	17,663
Social surplus	9,546,889	9,549,820	9,552,448	9,555,141	9,557,046	9,558,162

Table 6. Welfare Changes Due to Divestiture

Unit: 1,000 yen/h

	Base case	Scenario I	Scenario II	Scenario III	Scenario IV	Scenario V
Consumer surplus	7,881,240	8,089,235	8,166,766	8,219,693	8,208,371	8,399,704
Producer surplus	1,657,938	1,494,453	1,428,641	1,379,220	1,385,506	1,215,401
Congestion revenue	7,711	1,982	0	65	3,936	0
Social surplus	9,546,889	9,585,670	9,595,407	9,598,977	9,597,812	9,615,105

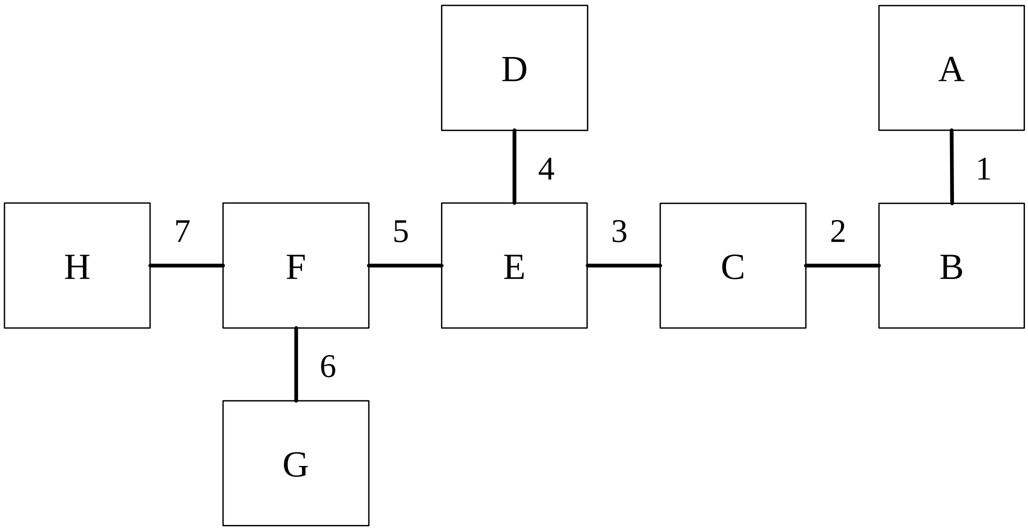

Figure 1. Market Areas and Interconnection Transmission Lines

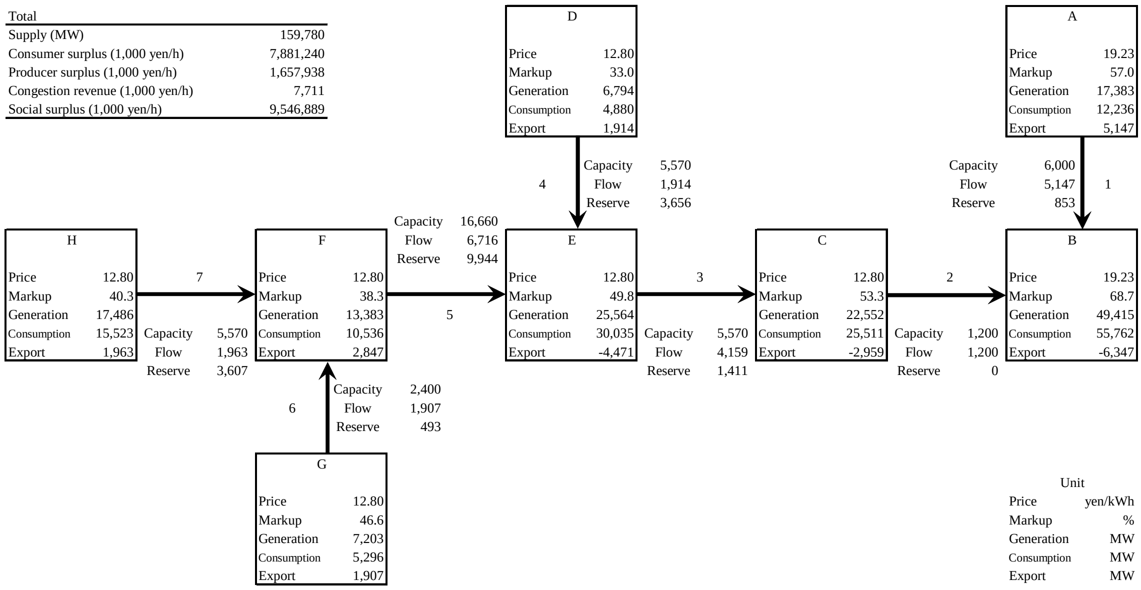

Figure 2. Cournot Competition among Eight Incumbent Generators

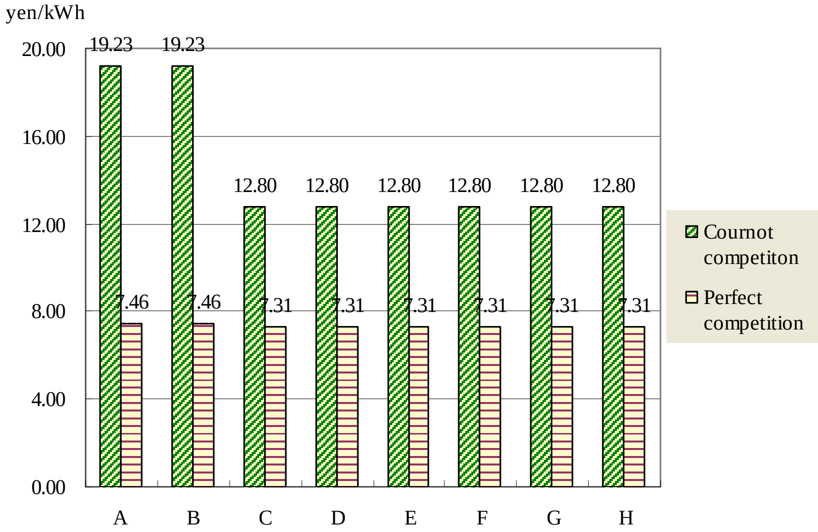

Figure 3. Comparison of Cournot and Perfect Competition: Energy Prices

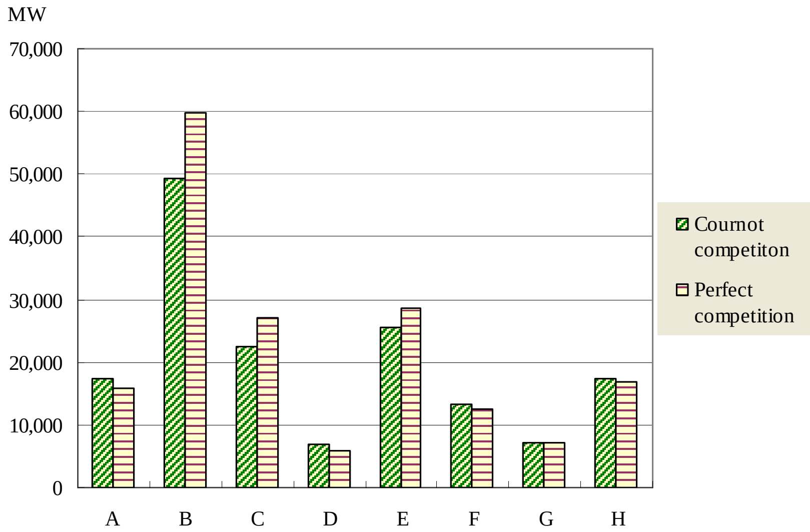

Figure 4. Comparison of Cournot and Perfect Competition: Quantities Generated

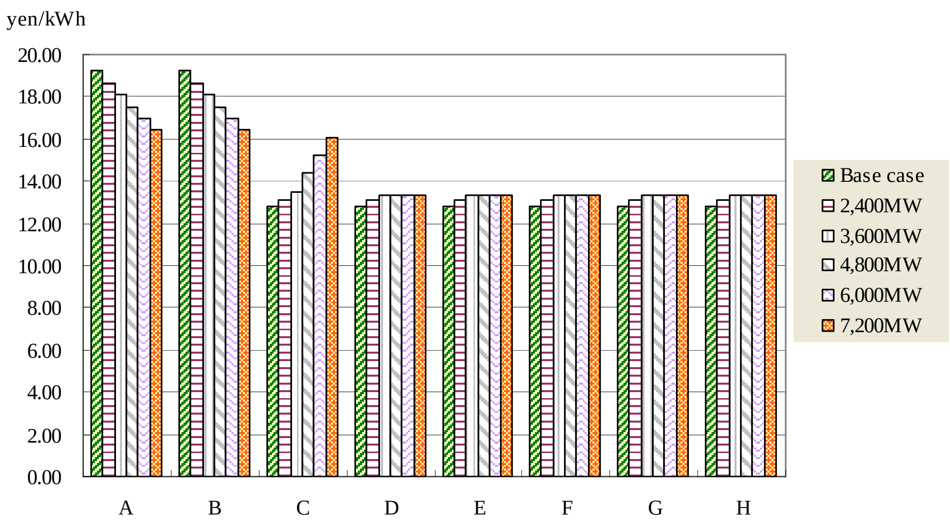

Figure 5. Price Changes Due to Upgrading of Transmission Capacity on Line 2

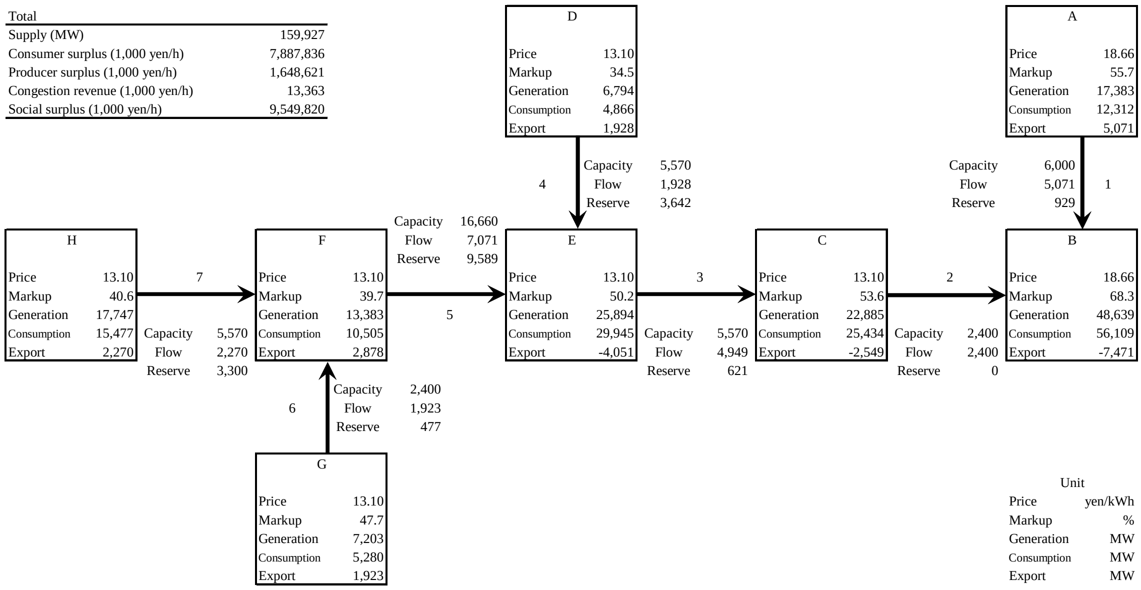

Figure 6. Upgrading of Capacity on Line 2 to 2,400MW

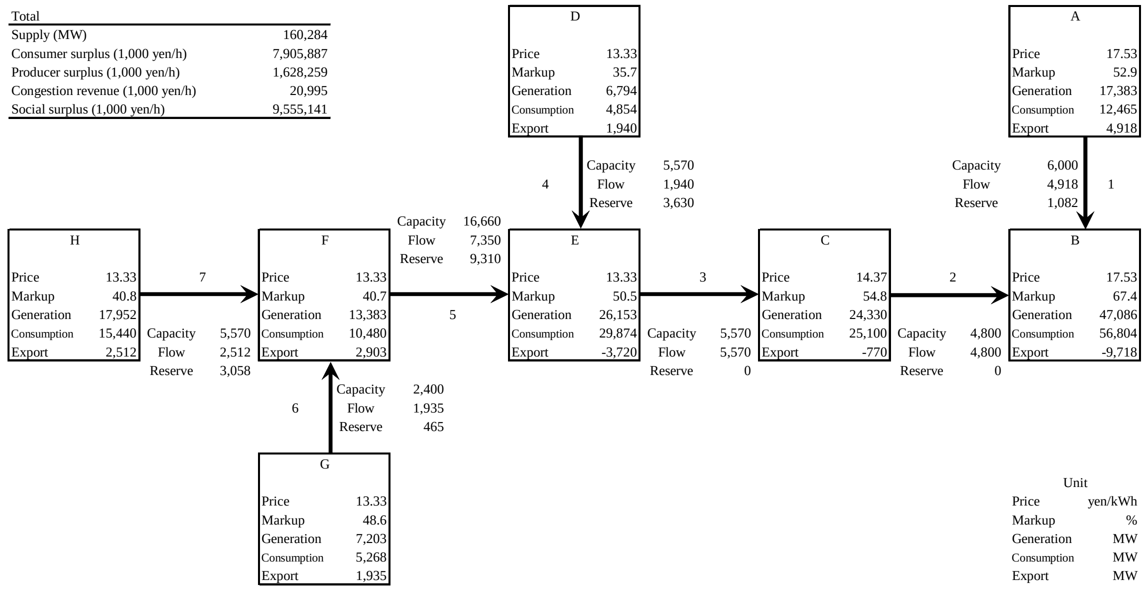

Figure 7. Upgrading of Capacity on Line 2 to 4,800MW

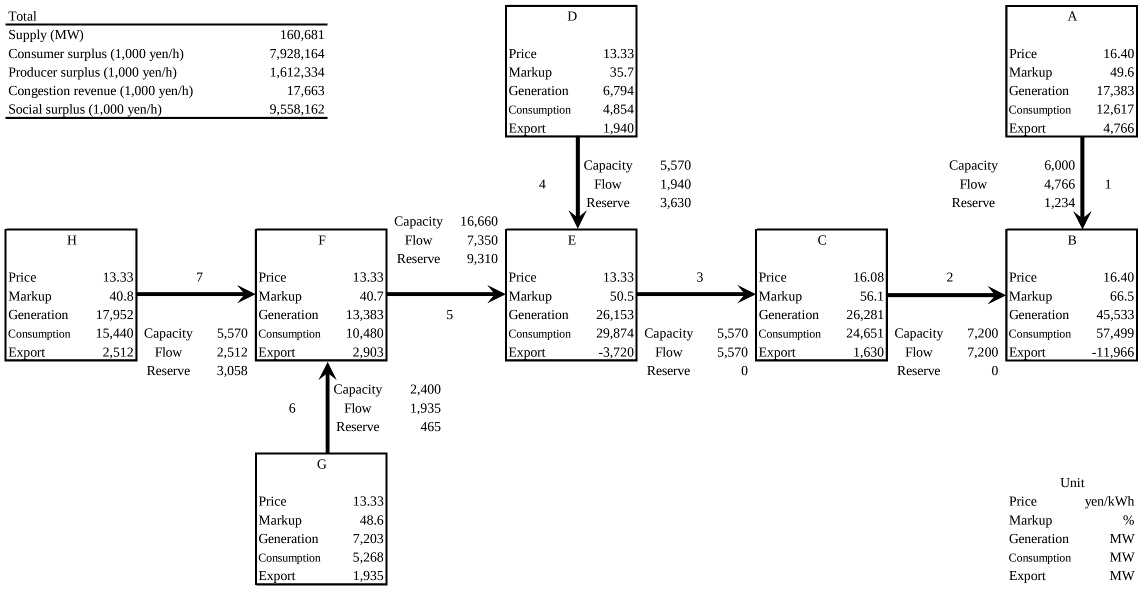

Figure 8. Upgrading of Capacity on Line 2 to 7,200MW

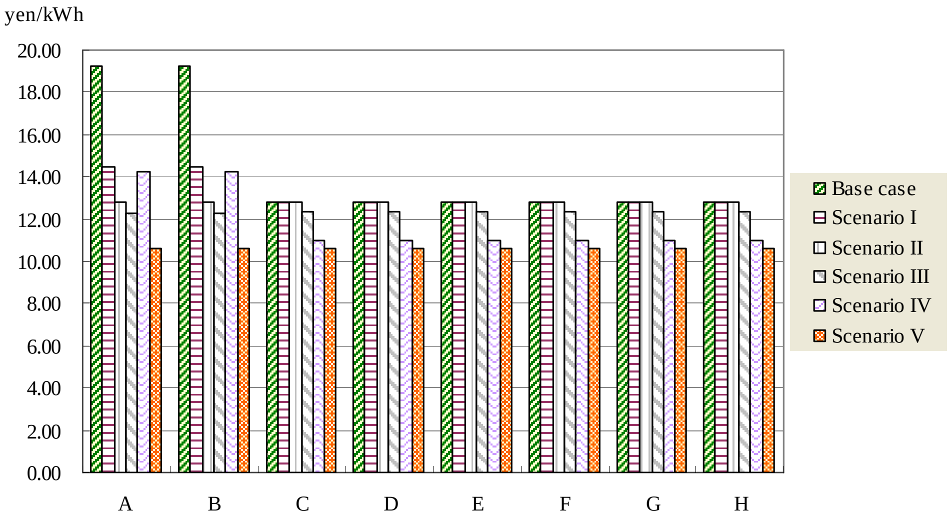

Figure 9. Price Changes Due to Divestiture

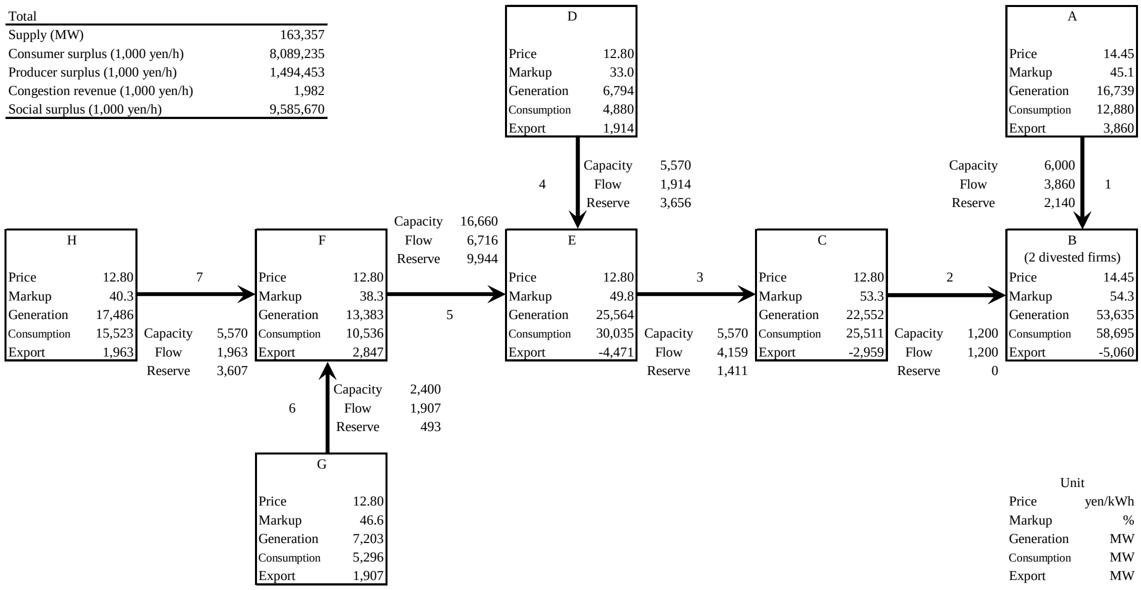

Figure 10. Divestiture Scenario I

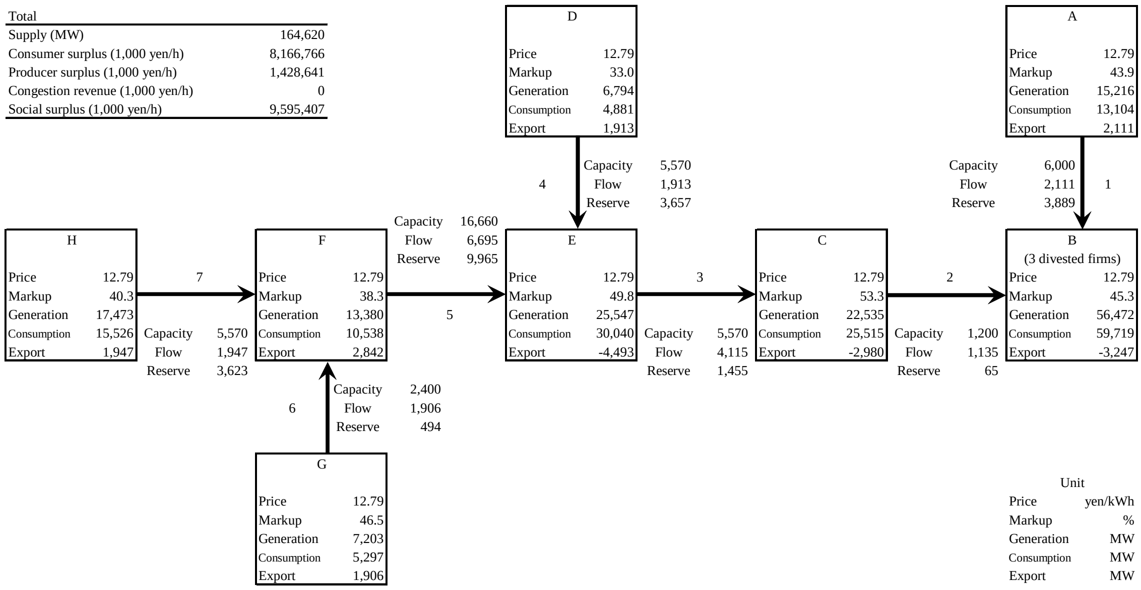

Figure 11. Divestiture Scenario II

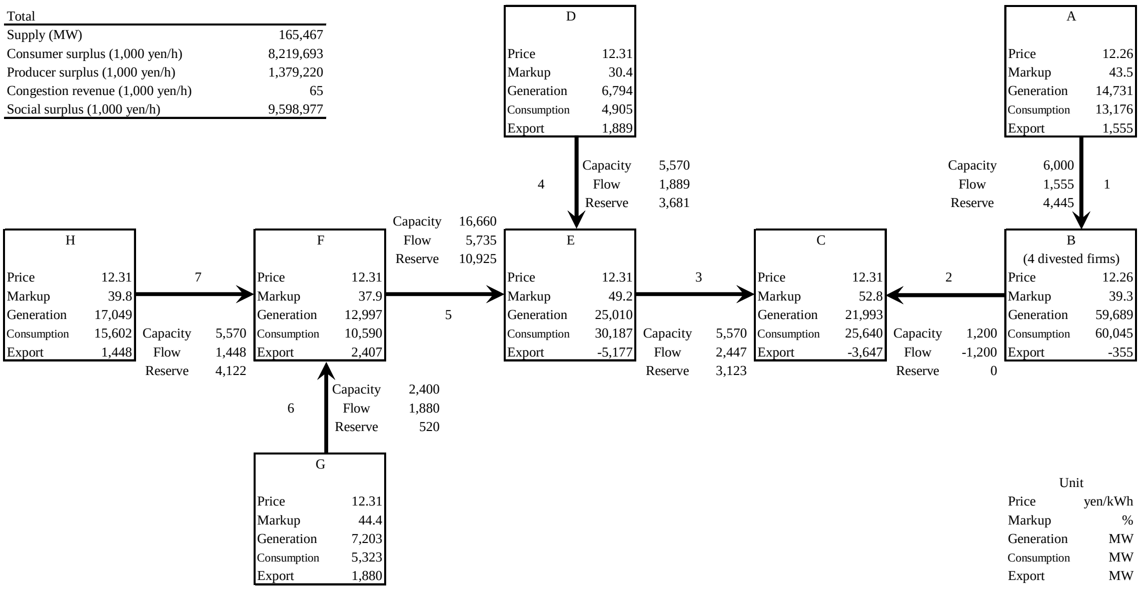

Figure 12. Divestiture Scenario III

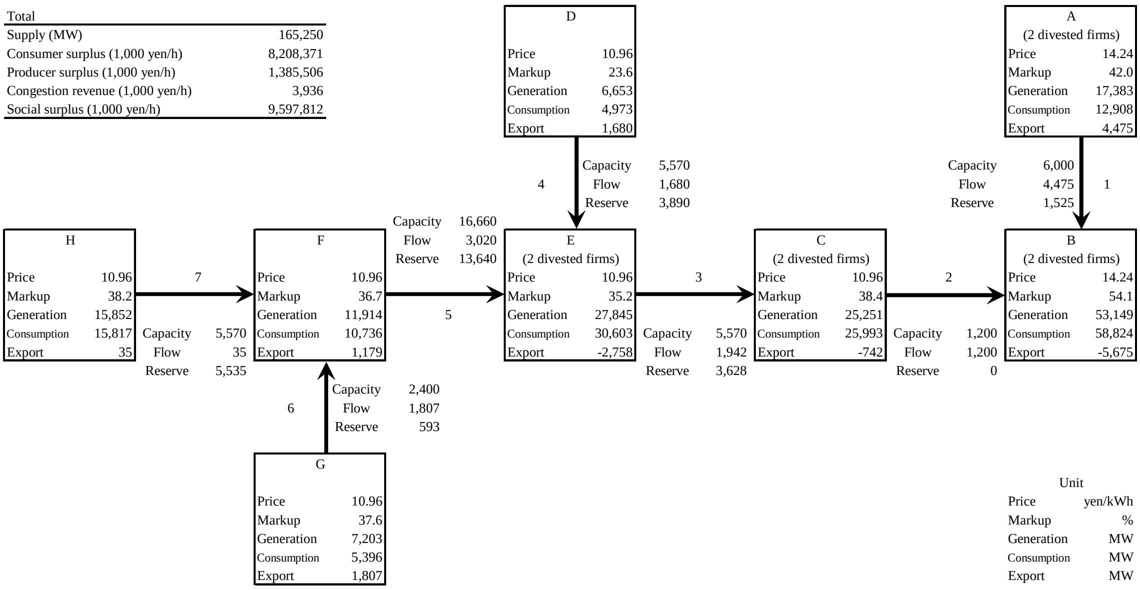

Figure 13. Divestiture Scenario IV

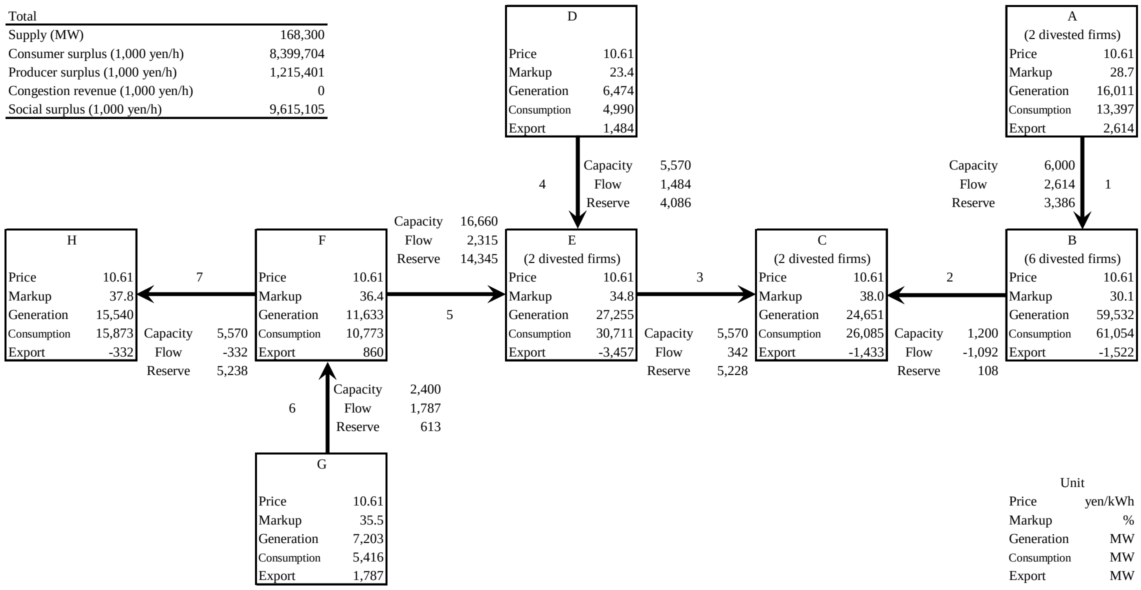

Figure 14. Divestiture Scenario V