The economic cost of mandatory reduction of electricity demand: A CGE analysis of the Korean case

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Abstract

In this paper, we used a CGE model featuring detailed energy sectors to estimate the economic costs of two alternative policies of reducing electricity consumption. The first policy is to increase the electricity tariffs by 10 percent across the board. The second policy is mandatory reduction of electricity consumption for large industrial customers, which impose the same reduction rate on all target users. The simulation results show that the latter has greater negative impact on the economy than the former. On annual basis, the former reduces real GDP by 0.062 percent and the latter by 0.085 percent when they both achieve the same overall power consumption reduction of 7.385 percent. These results confirm the principle that a market-based approach to balance supply and demand is more efficient than a command-and-control approach.

Keywords: CGE model, Electricity Price, Power Consumption, Mandatory Demand Control

JEL Classification: D58, L94, Q48

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First received, March 30, 2015; Revision received, May 2, 2015; Accepted, May 11, 2015.

1 Introduction

In 2013, Korea experienced severe power shortages. This was the result of the combined effects of chronic shortage of generation capacity, the record-breaking hot weather, and the unexpected suspension of many nuclear generating plants due to a fraud scandal involving uses of substandard parts. Of these factors, the shortage of capacity against the fast growing power demand is in large part attributed to the low electricity tariffs resulting from the government's reluctance to raise them to reflect rising fuel costs. Even during the period of critical power shortages, the government resorted to broad mandatory load curtailment measures to cope with the shortage at hand instead of adjusting the tariffs. This paper employs a computable general equilibrium (CGE) model to estimate the economic cost of such non-price based policy and compare it with the economic cost of higher electricity tariffs.

In Korea, the retail sector of the electricity industry is under monopoly by the government-owned enterprise of Korea electric power corporation (KEPCO). Naturally, the electricity tariffs are 100 percent controlled by the government. This market structure makes it extremely difficult to adjust electricity tariffs in times of increasing costs. The government likes to smooth out the effect of the increasing costs in order to minimize the shock to the economy. In the past, when the cost increases were moderate or infrequent, this policy did not cause any serious problems. However, maintaining the same policy when fuel costs kept increasing in leaps and bounds as in the 2000's proved to have had serious consequences. By late 2000's, the tariffs were on average more than 10 percent below cost. As a result, the electricity prices of Korea became one of the lowest among OECD members, and the power consumption per GDP became one of the highest among OECD members.

The rapid growth of electricity consumption was not anticipated by the planning authorities of the power sector, and so the construction of generation capacity failed to keep up with the load growth. The reserve ratio kept decreasing to fall below 5 percent in 2012. But it was not until Korea experienced a rolling blackout in 2011 that the seriousness of the situation was widely recognized. After the rolling blackout, which was completely unanticipated and caused great confusion, the whole country suddenly woke up to the reality of acute power shortage, of which no easy fix was to be found. Furthermore, the weather of Korea had become more extreme due to global warming. The summers became longer and hotter, and the winters exhibited more volatile temperatures. To make matters worse, a series of thorough inspections of Korea's nuclear power plants prompted by the Fukushima accident revealed that sub-standard parts were being used in many of the plants. Up to ten units were temporarily shut down for further inspection and parts replacement between 2012 and 2013. In the summer of 2013, Korea was bracing for the worst power shortage and a possible crisis.

Since it is impossible to increase the generation capacity in short order, the only way to avoid a real crisis was to control the demand. Heated debates took place on how to control the demand. Almost everyone agreed to the need to normalize tariffs to cover costs and rein in demand. But since it takes a long time to put a new tariff system in effect, emergency measures of demand control were adopted. In 2012, the government actively engaged in various demand management programs providing financial incentives for load reductions. However, after spending a big portion of the fund available for such purposes, the government introduced a mandatory load curtailment program in the winter of 2012. The program became stricter and broader in 2013. Thanks to the emergency measures of mandatory load curtailment, serious interruption of power supply was avoided in the summer and the winter of 2013. The power shortage was significantly relieved in 2014, as the supply caught up with the demand as many new power plants entered the system and the suspended unclear plants came back on line.

Though Korea was able to get over the crisis without major accidents and even without significantly increasing electricity tariffs in 2013, it does not mean that the power shortage was costless. Many office workers had to endure unpleasant room temperatures imposed by the government. On a more serious side, many factories had to cut production to meet the curtailment requirement. Unlike with tariff hikes, factories could not choose how much power consumption to reduce, since the curtailment requirement was applied uniformly across the board. For a company which would have paid a higher power price to fulfill important orders, the mandatory curtailment must have been more costly than higher tariffs. But how costly was the mandatory program for the whole economy? Was it better or worse than raising the overall tariffs, and by how much?

These are the questions that need to be addressed to assess the policy decisions. To answer these questions, we use a CGE model to compute the economic cost of the mandatory curtailment program applied uniformly, and compare it with the economic cost of a more market oriented policy of adjusting the tariffs to achieve the same overall reduction of power consumption. Since electric power is used in every business and household of the economy, a policy on its price or consumption must have effects on the whole economy. To evaluate such effects, therefore, a general equilibrium model is preferred over a partial equilibrium model. The results show that the mandatory demand curtailment policy is much more costly than tariff hikes in terms of their effects on GDP. When both achieve the same goal of reducing the total power consumption by 7.385 percent, the extra cost of the mandatory measure over the market based measure was 0.008 percent of GDP, amounting to 78 billion won, assuming that such reduction is needed only during the peak seasons of the summer and the winter. These results confirm the well-established proposition that price mechanism is more efficient than command and control. In addition, they provide estimates of the magnitude of the economic costs of the two approaches, offering guidance for policy discussions with regard to electricity demand management.

The remainder of the paper is organized as follows. The next section provides a brief introduction of the industry and market structure of the Korean power industry. It also discusses the recent power shortage and the government's responses in more detail. Section 3 explains of the CGE model and the parameters used. Section 4 explains the simulation method and shows the results. Section 5 concludes the paper.

Table 1. Generation capacity by fuel type (MW, %)

Fuel type	Nuclear	Coal	LNG	Oil	Pump & storage	Renewable	Total
2002	15,716	15,931	13,618	4,660	2,300	1,576	53,801
	29.2	29.6	25.3	8.7	4.3	2.9	100%
2012	20,716	25,128	21,885	5,293	4,700	4,084	81,806
	25.3	30.7	26.8	6.5	5.7	5.0	100%

Source: The 6th master plan of power demand and supply (Feb. 2013)

2 Korean power industry and regulations[3]

Table 1 provides summaries of the Korean power industry. The total installed capacity was about 54,000MW in 2002 and grew to about 82,000MW by the end of 2012. In 2012, coal, LNG and nuclear power capacities accounted for 30.7, 26.8 and 25.3 percent of the total capacity, respectively. The total capacity increased by 52.1 percent from 2002 to 2012, but the demand grew faster. During the same period, the per capita power consumption increased by 59.6 percent. As a result, the reserve ratio continued to decline until it fell below 10 percent in 2007 and reached the dangerously low level of 3.8 percent in the summer of 2012. On the demand side, Korea is peculiar in that the commercial and the industrial demands are very high. They each accounted for 29.9 percent and 53.2 percent of the total demand in 2011, respectively. The residential demand was meager 16.9 percent. This is partly due to the harsh inverse block-rate tariff applied to the residential use. This tariff system has six tiers by monthly usage, and the rate increases very rapidly starting from the lowest tier. The rate difference between the lowest tier and the highest tier is more than 11 times. As a result, the marginal price that an average household faces is very high.

Korea's entire electricity sector used to be a state-owned vertically-integrated monopoly of Korea electric power corporation (KEPCO) until 2000. In 2001, Korea started wide ranging restructuring of the electricity sector based on a road map stipulated in the Electricity Industry Restructuring Act. In the first stage (2001-2003), the generation sector was separated from KEPCO into six gencos as wholly-owned subsidiaries of KEPCO. Korea power exchange (KPX) was established to operate the system and at the same time run the wholesale power market.

The second stage of the restructuring was to commence in 2004 in which the distribution sector was to be divided into several regional distribution companies. They were to take charge of the retail operation as a monopoly in the respective regions. They were to participate in the wholesale market to purchase the electricity. The last stage was supposed to start in 2009, in which the regional retail markets were to be opened to

3 For more detailed account of Korea's electricity sector, please see Kim et al (2013).

competition so that the distribution companies could sell in other regions as well as in their own designated regions. The retail market was to be opened to independent retail companies, too.

However, the restructuring process stopped after completing only the first stage due to strong opposition from various parts of society, including the power sector labor union which preferred their status as government employees. The California fiasco in 2000-2001 also contributed to the cancelation of the rest of the restructuring plan. As a result, the Korean electricity sector is left with an industry structure and a market design which are meant for a temporary use during the transitional period of several years at the most. The generation sector is open to competition, but transmission, distribution and retail remain a monopoly by KEPCO. All the KEPCO generation subsidiaries remain wholly-owned by the parent company. They still account for over 80 percent of the total capacity. The rest is supplied by private generation companies which entered the market to sell electricity in the wholesale market.

The wholesale market, in which generation companies sell their power to KEPCO, is a mandatory pool operating on a day-ahead basis. It is a so-called cost-based pool (CBP), in which the generation companies bid their available capacity into the pool at prices pre-determined by regulation to equal the variable cost. The bid capacities are stacked in the order of the variable cost into an upward sloping curve similar to a supply curve in a competitive market. The wholesale price is determined as the variable cost of the last generator needed to meet the forecast demand. The price is called the system marginal price (SMP).

The retail tariffs are tightly controlled by government regulation. To change the tariffs, KEPCO should hold a board meeting first and then submit an application for changing the tariffs to the government. The Ministry of Trade, Industry and Energy reviews the application and decides to approve or reject it. But it must consult with the Ministry of Strategy and Finance to assess the impact on inflation. This process takes a long time and attracts wide and intense attention.

The Korean government is very reluctant to approve sharp increases in electricity tariffs, being highly sensitive to the criticism that the government is leading an inflationary trend instead of fighting it. So, when there is a big increase in the fuel cost, the government tends to reflect it in the tariffs gradually to minimize the shock to the economy. However, as mentioned in the introduction, maintaining the same policy when the fuel costs kept increasing rapidly as in the 2000's has left a big gap between the cost and the retail price of electricity in Korea. By 2012, the retail prices of electricity were on average more than 10 percent below the costs (Table 2). As these low prices persisted, the demand for electricity kept increasing faster than most expected.

It was not so much the absolute level of electricity prices as their relative level that had the biggest impact on the growth of electricity demand. Since the retail prices of other, mostly fossil, fuels kept up with the rising costs, electricity has become very cheap compared with other fuels. This prompted consumers to substitute electricity for other fuels for many purposes, especially for heating. Table 3 shows the trends in the relative prices and consumption of electricity, city gas, and heating oil (diesel/kerosene). Compared with 2002, heating oil prices more than doubled by 2011, but the price of electricity increased only by 21 percent. It is no surprise that electricity consumption increased by 63 percent while heating diesel consumption decreased significantly during the same period.

Table 2. The trend of electricity retail price cost recovery ratio (won/kWh, %)

	2007	2008	2009	2010	2011	2012	2013
Retail price	77.7	79.2	84.2	86.8	90.3	100.7	107.6
Total cost	83.0	102.0	92.1	96.3	103.5	113.9	113.1
Recovery ratio (%)	93.7	77.7	91.5	90.2	87.3	88.4	95.1

Table 3. Price and consumption change of final energies (2002-2011)

	Electricity	City gas	Diesel	Kerosene
Price index in 2011	121	161	265	239
Consumption index in 2011	163	136	73	43

Note: 2002=100

Table 4 shows the decline of the reserve ratio during the 11 years between 2001 and 2012. The supply reserve ratio reached as high as 17.1 percent in 2003 but steadily declined thereafter. It temporarily increased to 14.9 during the worldwide recession following the financial crisis in 2009, but resumed the decline to reach 3.8 percent in 2012. After experiencing a near blackout in 2011, the Korean government has been fully alert to the possibility of a major crisis in the following years. It spent over 600 million U.S. dollars on demand side management to offer generous financial incentives to large customers to reduce power consumption during critical hours. But the fund set aside for this purpose was fast depleted by the end of 2012, and the government had to resort to other emergency measures. A mandatory curtailment of power consumption was first implemented in the winter of 2011/2012 and was strengthened in the summer of 2013 with broader targets and deeper reduction goals.

Table 4. The trends of power reserve ratio (MW, %)

		'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12
Capacity reserve	MW	6,507	7,026	8,696	7,865	7,106	5,784	4,911	7,559	10,160	4,521	7,052	7,261
	ratio	15.1	15.3	18.4	15.3	13.0	9.8	7.9	12.0	16.1	6.5	9.8	9.8
Supply reserve	MW	5,574	6,340	8,103	6,264	6,187	6,189	4,493	5,725	9,420	4,458	5,442	2,791
	ratio	12.9	13.9	17.1	12.2	11.3	10.5	7.2	9.1	14.9	6.4	7.5	3.8

Source: The 6th master plan of power demand and supply (Feb. 2013)

The year 2013 was the worst. The already serious problem of excess demand was compounded by two additional, largely unexpected factors. One was the weather. The summer of 2013 was the hottest summer on record so far. The other was man-made. In the wake of the Fukushima accident of 2011, the safety standards of nuclear power plants were put under scrutiny. Unfortunately it turned out that many of them were using sub-standard parts. These plants were forced to shut down during the critical period of the summer for further inspection and parts replacement. By May 2013, as many as 10 out of 23 nuclear units with total capacity of 7,700MW were withdrawn from the system.

With a looming crisis for 2013, the government had to resort to the emergency measure of mandatory curtailment of power consumption. It was not yet ready to implement a new tariff system that could balance the market at real time. Nor was it likely that the short term response of the market to the price hikes be fast enough to fend off excess demand at peak hours. So the government adopted the non-price emergency measures first.

In the winter of 2012/2013, the government ordered a maximum room temperature of 20℃ for 6,500 large power consumers and 18℃ for all public buildings. It also ordered that customers with over 3000kW capacity should reduce their power consumption by a maximum of ten percent during the first two months of 2013. In the summer of 2013, with more nuclear power plants shut down and with record hot weather, stronger measures were implemented. The maximum mandatory reduction of power consumption was raised to 15 percent. The minimum room temperature for large consumers was set at 26℃ (28℃ for public buildings).

The emergency measures of mandatory demand control helped Korea avoid serious interruption of its power supply in the summer of 2013. But it does not mean that the emergency measures were costless. It directly affected people's welfare by limiting the use of electricity for air conditioning. It also affected the national economy by interfering with normal economic activities. If Korea had maintained an ideal electricity tariff system which reflects the market condition in real time, long term and short term price adjustments could have achieved market equilibrium without the need for quantity control. But this would have also affected the economy, as higher prices lead to lower electricity consumption. How big are the economic costs of these two alternative policies, and how do they compare with each other?

3 Construction of a computable general equilibrium (CGE) model

Since electricity affects every household and business in the economy, we need to look at a model that covers the whole economy and, at the same time, can analyze inter-sectoral relationships of the economy at the micro level. So, we resort to a CGE model of the Korean economy to estimate the economic cost of the mandatory demand control and compare it with the economic cost of higher electricity tariffs. Since our interest is in the comparative statics of the two scenarios, we use a static CGE model which does not consider the process in which the effects of the policy shocks propagate through the economy

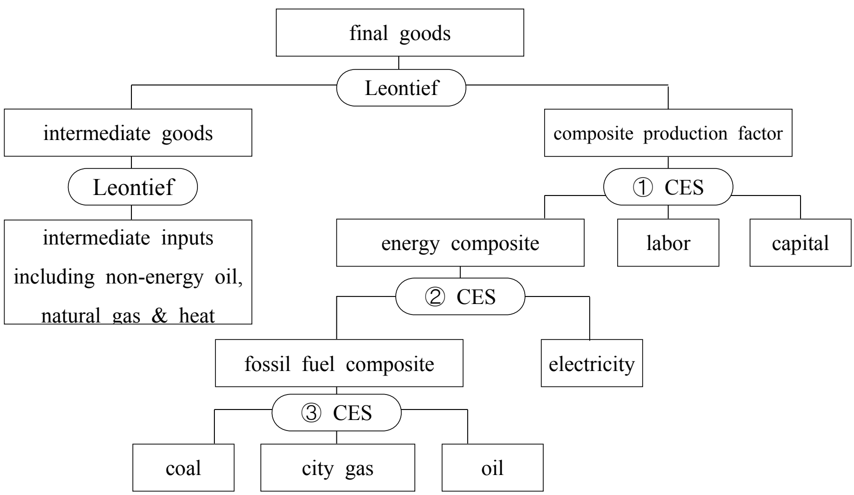
There are several studies of the effect of electricity price changes on the Korean economy. Son and Shin (1996) used a small open economy static CGE model to estimate the effect of tariff hikes on Korean industries and international trade. Hahn and Yoo (1997) and Hong (2003) also conducted similar studies. More recently, Park and Kim (2012) applied a static CGE model to examine the effects of restructuring various energy taxes. But these studies did not deal with the policy of quantitative restrictions. Wing (2009) provides a framework in which quantitative restrictions can be handled in a CGE model.

3.1 CGE model[4]

(1) Production sectors

We construct a CGE model best suited for our purpose. It has detailed energy sectors with seven sectors, so that we can capture the effect of electricity policy on alternative energy consumption. It uses a nested-CES production function in which electric power can be substituted for composite fossil fuel, comprised of coal, city gas, and oil. Other sectors, on the other hand, are simplified with broader industry classification. They were grouped into 27 sectors. Figure 1 describes the basic structure of the model of the economy and the production functions used in each sector.

Figure 1. The structure of the production sectors of the model of economy



4 The specific functional forms of the model are introduced in the appendix.

(2) Final demand sectors

- Household and government sectors

The model has one household representing the whole private consumption. It owns the primary factors of labor and capital, and has a Cobb-Douglas utility function. The government sector does not participate in any productive activity, but generates revenue from various taxes, which it uses for its own consumption, transfer payment or public savings. Government budget balance plays an important role in achieving the overall closure of the model economy.

- Foreign sector

We assume that the Korean economy is a small open economy in the world market. As such, it acts as a price taker in the international market. The final production of each good becomes either a domestic product or an export product according to a production possibility rendered by a constant elasticity of transformation (CET) function. The final proportion of the domestic and the export product is determined by the principle of profit maximization. The domestic supply of each good is the sum of the domestic product and the import product. Under the assumption that the domestic product and the import product are imperfect substitutes, the two comprise an Armington composite good to serve the domestic market. The Armington composite good is constructed through a minimum cost principle with a CES production function.

- Investment

Our model does not have an independent investment demand function. Instead, investment is assumed to be exogenously determined in accordance with the model closure rule.

(3) Model closure

To achieve a general equilibrium, a CGE model must obtain government budget balance, international balance of payments, and balance between savings and investment, as well as equilibrium in each of the product markets. Obtaining these three macroeconomic equilibria is called model closure. There are many different ways of achieving the closure, depending on which variables to fix and which to set free to balance the market. In our model, government savings and expenditure are allowed to adjust to accommodate the changes in the tax revenue. In the international trade, the exchange rate is free to change to obtain the balance of payments each year. In the savings-investment balance, it is the investment that moves freely to obtain the equilibrium.

3.2 Social accounting matrix (SAM)

The social accounting matrix (SAM) shows the amounts of economic transactions among the various sectors of the economy in the baseline year. The rows are for the income and the columns are for the expenditure of each sector. When the conditions of normal profit, market clearing equilibrium, and income equilibrium are met, the sum of all figures in each row and that of the corresponding column exactly match.

Table 6 shows the structure of the SAM used in our model. It is constructed with the figures provided in the I-O tables of the Korean economy published by the Bank of Korea and other macroeconomic statistics. It also takes advantage of the renewable energy I-O table published in 2012 (Shim and Oh, 2012). It is based on the Bank of Korea I-O table of 2008 but divides the energy sectors into 30 sub-sectors while grouping other sectors into bigger categories. Our model regroups the 30 energy sectors into seven sectors of crude oil, natural gas, heat, coal, oil, city gas, and electricity. As a result of using the amounts in the renewable energy I-O table of 2008, all the amounts and numbers for our model are for 2008.

3.3 Parameters

Of the many parameters in the CGE model, some are calibrated from the observed values from the real economy and the structural equations. However, there are other parameters that cannot be calibrated with such simple observations. These include most of the elasticities in the model. We should either estimate these parameters econometrically with a much broader set of data, or take the values which are established in other studies and widely accepted in the literature. We use the parameter values from Kang and Kim (2007), which are widely used in studies using the same nest-structure in the production function. Table 7 shows the parameter values in our model that are not calibrated but taken from other sources.

Table 6. The structure of social accounting matrix

		production sectors (34)		fiactors		final demand				Total
		activities	commodities	labor	capital	household	gov’t	savings -investment	net export	
sectors (34)	activities		domestic production							total product
	commodities	goods input				household demand	gov’t demand	invest demand	export total	demand
factors	labor	factor input								factor demand
	capital									
final demand	household			factor income			transfer			household income
	govern’t	production tax	sales tax, tariff			income tax				gov’t income
	savings-invest					household savings	gov’t savings		overseas savings	total savings
	net export		import					overseas investment		overseas expenditure
Total		Total input	Total supply	factor supply		household expenditure	gov’t expenditure	total investment	overseas income	

Table 7. Parameter assumptions

type	industries	value
elasticity of transformation between domestic and export products	primary	3.9
	manufacturing	2.9
	construction	0.7
	service	0.7
	energy	2.9
elasticity of substitution in Armington composite between domestic product and imports	primary	1.5
	manufacturing	2.5
	construction	2
	service	2
	energy	2/0.5
elasticity of substitution among labor, capital and energy composite	primary	0.5
	manufacturing	0.7
	construction	0.7
	service	0.7
	energy	0.4
elasticity of substitution between fossil fuel composite and electricity	primary	0.5
	manufacturing	0.7
	construction	0.7
	service	0.7
	energy	0.5
elasticity of substitution among oil, coal, and city gas	primary	0.6
	manufacturing	0.4
	construction	0.6
	service	0.6
	energy	0.4

Source: Kang and Kim (2007)

4 Estimating the economic costs of power demand control

Both price adjustment and quantity control entail reduced power consumption and affect the national economy. However, even when they result in the same reduction of overall power consumption, their effects on the economy are different. With the former, the reduction in power consumption differs across different consumers depending on their elasticity of power demand. Also, the price change can be easily implemented to all types of customers. However, the latter can be applied only to large consumers equipped with real time meters. Also, since the demand reduction target is applied to all the target customers without regard to their demand elasticity, all the affected customers end up reducing consumption by the same ratio. We incorporate these two policies into our model in two specific scenarios and compare their effects on the economy.

4.1 Two alternative policy scenarios

(1) Scenario 1: General increase of tariffs

The first scenario corresponds to the policy of rate hikes to cope with the excess demand, which is more in accordance with market principles. In a CGE model, a price increase driven by policy can be implemented as a tax increase as in the following equations.

$$PELT_i = (1+\tau_i)PEL_i$$

where $PELT_i$ is the electricity price applied to industry i, and τ_i is the extra tax rate applied to industry i. When the tax is imposed, $PELT_i$ replaces PEL_i in the model. We set $\tau_i = 10\%$ across the board, including the household sector.

(2) Scenario 2: Mandatory demand control

The second scenario is for mandatory demand control as was used in Korea. To compare the economic cost of this policy, we set the demand reduction targets so that the overall reduction in power consumption exactly matches that of Scenario 1. However, since direct demand control cannot be applied to all consumers, especially to households, we apply the demand control only to the industrial and government sectors. Therefore, the reduction target for the affected sectors is greater than the reduction target for the whole economy. As it turns out, Scenario 1 achieves the reduction of overall power consumption by 7.385 percent. To match this result, Scenario 2 imposes a 9.299 percent mandatory reduction on all affected sectors.

Since a CGE model does not allow disequilibrium in any of the markets, the quantitative restrictions should be implemented in the model in an indirect way in which differential taxes are imposed on different sectors so that the resulting reduction in consumption should meet the quantitative restriction (Wing, 2009). This is not exactly the same as quantitative restriction without price changes but can be regarded as an approximation to fit in the CGE framework.

Table 8 shows the eventual increase in electricity tariffs in each sector in the two scenarios. In Scenario 1, the rate increases by the same 10.290 percent in all the sectors including households.

In Scenario 2, the increases mostly take place in industrial sectors and by various percentages. In some sectors, the increase is over 20 percent while in others it is closer to 10 percent. They are all greater than 10 percent to match the same overall effect of Scenario 1 without involving the household sector.

Table 9 shows the electricity consumption changes in the two scenarios. As meant by design, all sectors reduce consumption by exactly the same 9.299 percent in Scenario 2. But in Scenario 1, the reduction differs significantly across different sectors because each sector responds to the rate hike differently according to its own need. In other words, each sector has a different elasticity of demand for electricity. The reduction ranges from 4.9 to 11.7 percent. In Scenario 1, the household sector is also affected by the rate hike and reduces power consumption by 9.44 percent, while in Scenario 2, it is barely affected. The substantial decrease in household power consumption alleviates the need for deeper reduction in industrial sectors in Scenario 1.

Table 8. Electricity tariff changes in the two scenarios

sectors	baseline level	Scenario 1		Scenario 2	
		level	change (%)	level	change (%)
agriculture, fishery, forestry	1.000	1.103	10.290	1.206	20.612
mining	1.000	1.103	10.290	1.176	17.581
food	1.000	1.103	10.290	1.145	14.513
textile & leather	1.000	1.103	10.290	1.134	13.426
wood & paper	1.000	1.103	10.290	1.145	14.466
printing	1.000	1.103	10.290	1.145	14.494
chemistry	1.000	1.103	10.290	1.139	13.888
non-metallic minerals	1.000	1.103	10.290	1.149	14.869
primary metallics	1.000	1.103	10.290	1.130	12.958
metallics	1.000	1.103	10.290	1.143	14.255
general machinery	1.000	1.103	10.290	1.144	14.395
electric machinery	1.000	1.103	10.290	1.150	14.979
precision machinery	1.000	1.103	10.290	1.150	14.967
transportation equip.	1.000	1.103	10.290	1.141	14.148
other manufacturing	1.000	1.103	10.290	1.142	14.176
water supply	1.000	1.103	10.290	1.151	15.093
construction	1.000	1.103	10.290	1.146	14.588
wholesale & retail	1.000	1.103	10.290	1.143	14.296
restaurants & hotels	1.000	1.103	10.290	1.145	14.529
transportation	1.000	1.103	10.290	1.147	14.686
communication & broadcasting	1.000	1.103	10.290	1.144	14.434
finance & insurance	1.000	1.103	10.290	1.143	14.280
real estate and business services	1.000	1.103	10.290	1.144	14.404
public service & defence	1.000	1.103	10.290	1.166	16.633
education & health service	1.000	1.103	10.290	1.152	15.174
social & other service	1.000	1.103	10.290	1.144	14.361
others	1.000	1.103	10.290	1.157	15.724
heat	1.000	1.103	10.290	1.209	20.908
coal	1.000	1.103	10.290	1.115	11.451
oil	1.000	1.103	10.290	1.210	20.953
city gas	1.000	1.103	10.290	1.137	13.657
electricity	1.000	1.103	10.290	1.043	4.303
household	1.000	1.103	10.290	1.003	0.318

Table 9 Electricity consumption changes in industrial sectors

sectors	baseline level (billion won)	Scenario 1 level	Scenario 1 change (%)	Scenario 2 level	Scenario 2 change (%)
agriculture, fishery, forestry	294.040	279.519	-4.939	266.697	-9.299
mining	82.545	77.698	-5.872	74.869	-9.299
food	427.015	398.613	-6.651	387.306	-9.299
textile & leather	794.682	737.600	-7.183	720.783	-9.299
wood & paper	795.938	742.548	-6.708	721.922	-9.299
printing	51.099	47.700	-6.653	46.348	-9.299
chemistry	1,926.781	1,792.692	-6.959	1,747.607	-9.299
non-metallic minerals	573.200	535.490	-6.579	519.897	-9.299
primary metallics	4,884.646	4,519.066	-7.484	4,430.415	-9.299
metallics	468.830	436.685	-6.856	425.232	-9.299
general machinery	413.811	385.615	-6.814	375.330	-9.299
electric machinery	1,452.769	1,357.786	-6.538	1,317.674	-9.299
precision machinery	61.466	57.444	-6.543	55.750	-9.299
transportation equip.	837.971	779.464	-6.982	760.046	-9.299
other manufacturing	83.988	78.238	-6.846	76.178	-9.299
water supply	298.624	279.404	-6.436	270.854	-9.299
construction	302.084	281.995	-6.650	273.992	-9.299
wholesale & retail	2,086.931	1,945.201	-6.791	1,892.864	-9.299
restaurants & hotels	850.234	793.664	-6.653	771.170	-9.299
transportation	498.417	465.369	-6.631	452.068	-9.299
communication & broadcasting	791.693	738.499	-6.719	718.073	-9.299
finance & insurance	725.404	676.195	-6.784	657.947	-9.299
real estate and business services	3,703.512	3,453.617	-6.748	3,359.116	-9.299
public service & defence	892.282	843.888	-5.424	809.307	-9.299
education & health service	2,335.518	2,189.305	-6.260	2,118.334	-9.299
social & other service	837.549	781.177	-6.731	759.664	-9.299
others	21.453	20.122	-6.205	19.458	-9.299
heat	151.182	143.711	-4.941	137.123	-9.299
coal	113.664	103.838	-8.645	103.094	-9.299
oil	539.363	512.523	-4.976	489.207	-9.299
city gas	13.875	12.799	-7.754	12.585	-9.299
electricity	394.529	348.476	-11.673	357.841	-9.299
household	7,632.385	6,911.877	-9.440	7,599.069	-0.437

4.2 Economic consequences of the two policy scenarios

Table 10 summarizes the effects of the two policies derived from the simulation outcomes of the CGE model. In Scenario 1, GDP decreases by 0.062 percent as a result of 10 percent increase in the electricity tariff. The consumer price index and the producer price index rise by 0.307 percent and 0.234 percent, respectively. The overall size of international trade also shrinks, but the reduction in exports is greater than that of imports. As a result, the Korean currency (won) depreciates by 0.237 percent.

The adverse impact on the whole economy is greater for Scenario 2. Real GDP decreases by 0.085 percent, which is about 37 percent greater than in Scenario 1. The negative impact on international trade is also greater: both exports and imports shrink more, and the exchange rate also rises more. The simulation generates estimated effects on price indexes in Scenario 2, but since they are based on the assumption that the quantity control is achieved through tariff hikes, which is not the case in reality, we'd rather not place too much meaning on them.

Note that the figures in Table 10 over-estimate the impact of the two policies on the economy. It is because the power shortage matters only during the peak months of the summer and the winter. They are at most two months in the summer (July and August) and two months in the winter (December and January). Therefore, the actual cost to the economy is about one third of the cost shown in Table 10: real GDP should decrease by 0.021 and 0.028 percent respectively in Scenario 1 and 2.

Table 10. Changes in macroeconomic indicators

(Units: bill. won, %)

	baseline level	Scenario 1		Scenario 2	
		level	change (%)	level	change (%)
real GDP	1,025,896.925	1,025,259.515	-0.062	1,025,026.711	-0.085
real household expenditure	579,915.241	577,509.771	-0.415	577,447.895	-0.425
real gov't expenditure	139,563.407	141,331.467	1.267	141,160.540	1.144
real investment	318,610.531	318,610.531	0.000	318,610.531	0.000
export	550,318.936	547,493.470	-0.513	546,965.178	-0.609
import	562,511.191	559,685.725	-0.502	559,157.433	-0.596
consumer price index	1.000	1.003	0.307	1.003	0.307
producer price index	1.000	1.002	0.234	1.004	0.383
exchange rate	1.000	1.002	0.237	1.004	0.394

5 Conclusion

In this paper, we used a CGE model with detailed energy sectors to estimate the economic costs of two alternative policies of reducing electricity consumption. The first policy is to increase the electricity tariffs by 10 percent across the board. The second policy is mandatory reduction of electricity consumption for large industrial customers, which impose the same reduction rate on all target users. The simulation results show that the latter has greater negative impact on the economy than the former. On an annual basis, the former reduces real GDP by 0.062 percent and the latter by 0.085 percent when they both achieve the overall power consumption reduction of 7.385 percent. Since the demand reduction is required only during the four months of peak load, their actual impact on the economy is 1/3 of the above estimates. These results confirm the economic principle that the market-based approach to balance supply and demand with price adjustment is more efficient than the command-and-control approach favored by the Korean government.

Our results show that the direct measures of demand control do in fact incur more economic costs than the market-oriented measures of tariff changes, and further provide an estimate of magnitudes of the economic costs. They imply that a more efficient way of achieving reliability in the electricity system is to develop well-functioning electricity markets at both wholesale and retail levels than to resort to mandatory demand control every time there emerges excess electricity demand. The impact of electricity price changes in our results is comparable to those from other studies. Hahn and Yoo (1997) reported that a 30 percent price increase led to a 0.128 percent reduction of GDP. In Hong's study (2003), a 12 percent price increase resulted in a 0.036 percent reduction in GDP. Park and Kim (2012) reports a much greater impact of a 0.203 percent drop in GDP by a 5 percent price increase. Since they do not exactly report the parameters used in their model, it is not possible to determine the causes of this big difference.

One limitation of our approach is that we translated the quantitative restrictions into price changes to achieve the same reduction targets. This is due to the nature of CGE models that does not allow disequilibrium.

But as a result of this approximation, the mandatory demand reduction policy in our model is not exactly the same as the actual demand reduction policy, in that the actual policy does not accompany tariff changes. When more sophisticated CGE models are developed in the future that can handle disequilibrium, we will be able to estimate the impact of quantitatively restrictive policies more accurately.

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Appendix: Production and utility functions in the CGE model

Production function for final good *i*

$$QA_i = \min\left[\frac{QINTA_i}{aint_i}, \frac{QCF_i}{acf_i}, \frac{ACTT_i}{ta_i}\right]$$

$QINTA_i$: composite intermediate good for i
QCF_i: composite production factor for i
$ACTT_i$: production tax for i

Production function for composite intermediate good for *i*

$$QINTA_i = \min\left[\frac{QINT_{ji}}{aint_{ji}}\right]$$

$QUNT_{ji}$: input of intermediate good into production sector i

Production function for composite production factor for final good *i*

$$QCF_i = \alpha 1_i\left[\delta l_i QL_i^{-\rho 1_i} + \delta k_i QK_i^{-\rho 1_i} + \delta ce_i QCE_i^{-\rho 1_i}\right]^{-\frac{1}{\rho 1_i}}$$

QL_i: labor input for final good i
QK_i: capital input for final good i
QCE_i: energy composite input for final good i

Production function for energy composite for final good *i*

$$QCE_i = \alpha 2_i\left[\delta el_i QEL_i^{-\rho 2_i} + \delta cfu_i QCFU_i^{-\rho 2_i}\right]^{-\frac{1}{\rho 2_i}}$$

QEL_i: electricity input for final good i
$QCFU_i$: fossil fuel composite input for final good i

Production function for fossil fuel composite for final good *i*

$$QCFU_i = \alpha 3_i\left[\sum_{fu} \delta f_{fu,i} QINT_{fu,i}^{-\rho 3i}\right]^{-\frac{1}{\rho 3_i}}$$

$QINT_{fu,i}$: fossil fuel input for final good i

Utility function of the representative household

$$U(QH)=\prod_i QH_i^{\beta_i}$$

QH_i: consumption of final good i

Transformation function of domestic product and export product

$$QA_i=\alpha t_i\left[\delta ex_i QEX_i^{\rho t_i}+\delta d_i QD_i^{\rho t_i}\right]^{\frac{1}{\rho t_i}}$$

QA_i: production of final good i
QD_i: domestic product of final good i
QEX_i: export product of final good i

Production function for Armington composite for final good *i*

$$QQ_i=\alpha q_i\left[\delta m_i QM_i^{-\rho q_i}+(1-\delta m_i)\,QD_i^{-\rho q_i}\right]^{-\frac{1}{\rho q_i}}$$

QQ_i: Armington composite for final good i
QD_i: domestic product of final good i
QM_i: import product of final good i