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Investment Incentives for Nuclear Generators and Competition in the Electricity Market of Korea

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1. Introduction

There is huge uncertainty about the true costs of producing electricity using uranium as fuel, which has grown even bigger after the Fukushima Daiichi accident. The expected cost of nuclear power generation must have increased significantly too after Fukushima as the accident showed that the ultimate cost from an accident could be far higher than had been estimated previously. Despite the increased expected cost and higher uncertainty, most countries seem to estimate the ultimate cost of generation using nuclear is lower than the cost of generation using other fuel sources. Many countries that postponed the construction of new nuclear power plants recently decided to go ahead with the construction plan. Korea continued to build a fairly large number of new nuclear power plants despite the Fukushima accident and recently announced a plan to expand its fleet of nuclear power plants further.

The countries that made the decision to allow the construction of new nuclear power plants has to come up with a way according to which new nuclear power plants are built. In countries in which the electricity industry is monopolized by the state, the decision on the construction of new nuclear power plants is made along with the decision to build other types of power plants by solving a dynamic optimization problem for the electricity industry using a central planning approach. In countries or regions in which the electricity industry is monopolized by a private firm or an SOE that is subject to a price regulation that is cost based or profitability based, the government also tries to calculate a generation mix that would lead to the maximization of the social welfare or minimization of the total costs of generation given a demand profile in the future, although the decision making process is slightly different from that in countries whose electricity industry are run directly by the state monopoly.

In both cases, it is the government that ultimately makes decisions on how much new capacity of each generator type should be built in each point of time in the future. Such a decision making process generally shields generation companies from the risks involved in investment in generation capacity and forces consumers and taxpayers to bear all the risks. In particular, all of the risks involved in investment in nuclear power plants are borne by consumers and taxpayers.

However, in countries or regions in which competition in the wholesale electricity market is allowed, investment in generation capacities are borne in part by generation companies and retail companies. Optimality in investment is not automatically guaranteed by competition in those markets due to several factors that characterize the electricity market. Ultimately, optimality of investment in generation capacity depends crucially on the market rules that govern competition between firms in the wholesale market. Optimality in the investment in nuclear power plants can be affected adversely in competitive wholesale markets by the following factors.

First, even in countries in which the expected value of the levelized cost of nuclear power generation is lower than that of other types of generation, high degree of uncertainty about the ultimate cost of nuclear power generation can deter individual generation companies or investors from investing in nuclear capacity that is socially optimal.

Second, politically determined ceiling on nuclear capacity can fall short of the socially desirable level of nuclear capacity.

Third, market rules can distort the incentives for investment in various generators, including nuclear generators.

Distortion in investment in nuclear power generators is an important problem that affects the efficiency of the electricity market. Suboptimal investment in nuclear generators generally leads to suboptimal performance in the overall electricity market, including suboptimal capacity level and suboptimal generator mix that entail higher total generation costs and opportunity costs of consumers from the unserved load.

The objective of this paper is to analyze the procedure that determines investments in generators and the market rules that determine the revenues of generators used in the wholesale electricity market of Korea to evaluate their performance and to propose a set of measures that could potentially improve the efficiency of investment in generation capacities. In addition, we also touch on the efficiency of investment in an alternative nuclear generation technology, namely SMART - the small reactor developed in Korea, under the current rules that govern investment and resource allocation in the wholesale market[1].

There are few, if any, previous studies on the efficiency of investment in the nuclear power generators in Korea after the restructuring of the electricity market. Nam (2012) analyzed the market rules used in the wholesale market of Korea and found out that the capacity pricing rule has no firm economic ground and that as a result is likely to lead to inefficiency in investment in generation facilities in general under a free entry assumption. Nam (2012) also found out that bojunggesoo is likely to distort the investment incentives under a free entry assumption. But there is no previous study on the effect of the market rules on the efficiency of investment in nuclear power plants in Korea when entry into the generation stage is regulated as is the case in Korea.

Literature on the effect of the market rules on investment in other restructured markets generally focus on the missing money problem that is due to the ceiling on the energy price and the design of the capacity pricing rule aimed at alleviating the missing money problem[2]. There are few if any studies on the efficiency of investment in generation capacity in a restructured market outside of Korea when there exist entry barriers to new investment in generation capacities as well as government intervention in the market that affects the wholesale energy prices. In most restructured electricity markets, energy prices are determined in the market, and the government is not allowed to intervene in the market to affect the market price. Further, there is no regulation on the investment in new generation

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[1] SMART stands for System-Integrated Modular Advanced Reactor.

[2] See for instance Ausubel and Cramton(2010), Cramton and Stoft (2015), Joskow (2006), and Joskow and Tirole (2007) for the reasons for the inefficiency of energy only market and why capacity market can alleviate the missing money problem. Ausubel and Cramton (2010) and Cramton and Stoft (2005) also discuss the superiority of the forward market approach to the capacity price over the spot market approach.

capacity that is based upon the projected future demand for electricity. In other words, there is no restructure market outside of Korea in which the government affects the energy prices and regulates the entry into the market for new generation capacity[3].

Korea restructured its electricity market and established a competitive wholesale market in 2001. Korean wholesale electricity market has several characteristics that are peculiar. On the investment side, Korean government does not allow free entry into the nuclear generation part of the market. It allows only Korea Hydro and Nuclear Corporation (KHNC henceforth) to build, own, and operate a nuclear generator. It also fixes the total capacity of nuclear generators at a level that is far lower than the level that is consistent with the minimization of the total cost of generation. Thus there arises the possibility that nuclear generators earn higher than normal profits on their investment in the wholesale market.

In the wholesale market, generators earn revenues from selling both energy and capacity. The market rules require that each generator bid a price for the energy it generates based on the variable cost of generation, leading to an equilibrium energy price called the system marginal price (SMP). The market rules that determine the capacity price are absurd and reflect neither the opportunity cost of capacity in the spot market for capacity nor the opportunity cost of capacity in the future market for capacity. In addition, the government applies discount factors, called bojunggesoo, to the price of energy sold by the generation companies that are subsidiaries of Korea Electric Power Corporation (KEPCO henceforth). The bojunggesoo vary according to the type of the generator and are arbitrarily determined by the government. Nuclear generators are subject to larger discount on the margin between SMP and the variable cost of generation than other generator types. The formula that determines the capacity price reflects the opportunity cost of capacity neither in SR nor LR.

Nuclear generators that had been built before restructuring would earn higher than normal profits on their investment, which had been made under a loose rate of return type regulation,

[3] In other words, there was no need to study the problem this paper tries to address in other restructured markets outside of Korea. There may be a regulation on the investment on building nuclear power plants or due to political constraints or on building coal-fired power plants due to environmental regulation in some restructured markets. However, there is no barrier to investment in other types of generators in those markets so that the efficiency of investment in generation capacity can be ensured subject to the constraint on the investment in nuclear or coal-fired generators.

if there were no bojunggesoo applied to them. New nuclear reactors that were or would be built after 2001 are also expected to earn higher than normal profits if there were no bojunggesoo[4]. However, the discount that the Korean government applies to the price of energy sold by nuclear generators change the return on investment in new nuclear generators in a fundamental way and introduces significant uncertainty about the profitability of new nuclear generators.

The combination of the regulation on investment in nuclear generators and the market rules affect the efficiency of the wholesale electricity market can lead to inefficiency in the wholesale market through its effect on the incentives of KHNC and its managers and on entry by potential competition. Its effect on potential competition is not limited to competition with the nuclear generators owned and operated by firms other than KHNC. The regulation on investment in nuclear generators and the market rules also determines the profitability of new nuclear generators that are based on a new technology, such as small modular reactors. It can also affect the efficiency of the wholesale market by changing the profitability of other types of generators.

This paper proceeds as follows: In section 2, we describe the performance of nuclear generators and KHNC in the wholesale market, and in section 3, we describe the regulation on investment in nuclear generators enforced by the government in Korea and the market rules used in the Korean wholesale market, focusing on the capacity price, energy price, and bojunggesoo that apply to nuclear generators, and analyze their effects on the efficiency. We also analyze their effects on the efficiency of the wholesale market and propose a set of alternative mechanisms for market rules, focusing on nuclear generators. In section 4, we review the process of developing and commercializing new nuclear reactors, including a small modular reactor model developed in Korea, and discuss efficient ways to allow construction and operation of small modular reactors.

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[4] Korea has 23 nuclear generators in operation as of Dec. 2013. Only two new nuclear generators have been built since restructuring, Shinkori #2 and Shinwolsung #1, both of which started commercial operation in 2012. KHNC is currently building 5 new nuclear generators and are planning to build several more in the next 10 to 20 years.

2. Performance of nuclear generators in the wholesale market of Korea

Share of nuclear power generation in the wholesale electricity market can be measured in several different ways. In terms of the capacity, nuclear had the largest share at 30.7% in 2001, followed closely by coal. Its share kept declining until 2011 and began to bounce back in 2012 after the completion of new nuclear generators. Share of coal has been remarkably stable during this period while the share of LNG increased from 20.5% in 2001 to 24.3% in 2012. [Table 2-1] below contains statistics for the capacity of various fuel sources since restructuring.

[Table 2-1 Capacity of various fuel sources since restructuring]

(Unit: MW,%)

year (market share)	Nuclear energy	coal	domestic coal	LNG	oil	Pump and storage	hydro	Etc.	Total
2001	14,716 (30.7)	14,240 (29.7)	1,291 (2.7)	9,818 (20.5)	4,810 (10.0)	2,300 (4.8)	775 (1.6)	10 (0.0)	47,959
2002	15,716 (30.5)	14,740 (28.6)	1,191 (2.3)	10,868 (21.1)	4,837 (9.4)	2,300 (4.5)	794 (1.5)	1,021 (2.0)	51,467
2003	16,716 (29.4)	15,622 (27.4)	1,191 (2.1)	12,253 (21.5)	5,443 (9.6)	2,300 (4.0)	799 (1.4)	2,602 (4.6)	56,925
2004	17,716 (30.1)	16,495 (28.0)	1,125 (1.9)	12,403 (21.0)	5,447 (9.2)	2,300 (3.9)	804 (1.4)	2,655 (4.5)	58,943
2005	17,716 (28.8)	17,592 (28.6)	1,125 (1.8)	13,817 (22.4)	5,517 (9.0)	2,300 (3.7)	809 (1.3)	2,679 (4.4)	61,554
2006	17,716 (27.1)	18,594 (28.4)	1,125 (1.7)	13,895 (21.3)	5,717 (8.7)	3,900 (6.0)	1,583 (2.4)	2,828 (4.3)	65,357
2007	17,716 (25.9)	20,478 (29.9)	1,125 (1.6)	14,945 (21.8)	5,677 (8.3)	3,900 (5.7)	1,592 (2.3)	3,010 (4.4)	68,443
2008	17,716 (24.9)	22,898 (32.1)	1,125 (1.6)	14,977 (21.0)	5,677 (8.0)	3,900 (5.5)	1,602 (2.2)	3,361 (4.7)	71,256
2009	17,716 (24.2)	23,799 (32.5)	1,125 (1.5)	15,742 (21.5)	5,707 (7.8)	3,900 (5.3)	1,615 (2.2)	3,733 (5.1)	73,335
2010	18,716 (24.2)	23,925 (30.9)	1,125 (1.5)	18,182 (23.5)	5,665 (7.3)	3,900 (5.0)	1,621 (2.1)	4,227 (5.5)	77,361
2011	18,716 (23.7)	24,254 (30.8)	1,125 (1.4)	18,423 (23.4)	5,337 (6.8)	4,700 (6.0)	1,712 (2.2)	4,560 (5.8)	78,827
2012	20,716 (25.1)	24,312 (29.5)	1,125 (1.4)	20,058 (24.3)	5,100 (6.2)	4,700 (5.7)	1,738 (2.1)	4,778 (5.8)	82,527

Source: Reproduced from Korea Power Exchange (2013)

In terms of the total electricity generated, nuclear had a higher than 40% share in 2001. But its share dropped to 30.4% in 2012, reflecting the decrease in the proportion of nuclear generators in the total capacity and the higher capacity factor of combined cycle generators due to the shortage in the generation capacity in most hours compared to demand. Proportion of LNG jumped from 8.6% in 2001 to 22.3% in 2012. Proportion of coal remained virtually unchanged at around 40%. Following [Table 2-2] contains information on distribution of shares of various fuel sources in terms of electricity generated since restructuring.

[Table 2-2 Distribution of shares of fuel sources in terms of electricity generated]

(Unit: GWh,%)

year (marktet share)	Nuclear energy	coal	domestic coal	LNG	oil	Pump and storage	hydro	Etc.	Total
2001	80,528 (40.5)	78,575 (39.5)	4,734 (2.4)	17,040 (8.6)	15,585 (7.8)	1,551 (0.8)	1,008 (0.5)	6 (0.0)	199,027
2002	114,684 (40.7)	108,485 (38.5)	6,093 (2.2)	31,395 (11.1)	17,326 (6.1)	2,068 (0.7)	1,770 (0.6)	47 (0.0)	281,871
2003	124,412 (41.5)	110,408 (36.9)	6,346 (2.1)	34,152 (11.4)	19,167 (6.4)	1,978 (0.7)	2,438 (0.8)	608 (0.2)	299,509
2004	125,142 (39.3)	117,644 (37.0)	5,247 (1.6)	47,489 (14.9)	17,843 (5.6)	1,527 (0.5)	2,382 (0.7)	771 (0.2)	318,045
2005	140,367 (41.4)	124,002 (36.6)	5,229 (1.5)	48,281 (14.2)	16,704 (4.9)	1,503 (0.4)	2,129 (0.6)	645 (0.2)	338,864
2006	142,114 (40.0)	129,296 (36.4)	5,184 (1.5)	57,074 (16.1)	15,482 (4.4)	1,741 (0.5)	3,106 (0.9)	872 (0.2)	354,869
2007	136,599 (36.5)	143,612 (38.4)	5,501 (1.5)	65,666 (17.5)	16,556 (4.4)	1,398 (0.4)	3,591 (1.0)	1,460 (0.4)	374,384
2008	144,254 (36.8)	160,402 (40.9)	6,326 (1.6)	65,155 (16.6)	8,965 (2.3)	2,480 (0.6)	3,007 (0.8)	1,732 (0.4)	392,323
2009	141,123 (34.8)	178,839 (44.1)	7,298 (1.8)	57,555 (14.2)	12,869 (3.2)	2,814 (0.7)	2,763 (0.7)	2,430 (0.6)	405,692
2010	141,894 (32.2)	183,359 (41.6)	7,649 (1.7)	85,173 (19.3)	11,841 (2.7)	2,774 (0.6)	3,626 (0.8)	4,551 (1.0)	440,868
2011	147,763 (32.0)	185,778 (40.2)	7,777 (1.7)	96,005 (20.8)	9,568 (2.1)	3,214 (0.7)	4,484 (1.0)	7,753 (1.7)	462,343
2012	143,548 (30.4)	184,603 (39.1)	8,020 (1.7)	105,177 (22.3)	14,524 (3.1)	3,634 (0.8)	3,854 (0.8)	8,435 (1.8)	471,795

Source: Reproduced from Korea Power Exchange (2013)

The fall in the share of nuclear in the total electricity generated naturally led to a similar fall in the share of KHNC. The following [Table 2-3] summarizes the market share distribution of generation companies in terms of the electricity generated. KHNC’s share decreased by nearly 25% while the shares of 5 other subsidiaries of KEPCO have been stable. The decrease in the share of KHNC is matched by the almost the same increase in the combined share of non-KEPCO generation companies.

[Table 2-3 Market share distribution in terms of electricity generated]

(Unit: :GWh,%)

year (market share)	KHNC	Namdong	JUngbu	Seobu	Nambu	Dongseo	Etc.	Total	Rate of increase from previous year
2001	81,408 (40.9)	22,803 (11.5)	19,885 (10.0)	25,215 (12.7)	25,151 (12.6)	24,378 (12.2)	186 (0.1)	199,027	-
2002	115,847 (41.1)	29,661 (10.5)	30,883 (11.0)	36,215 (12.8)	35,293 (12.5)	32,891 (11.7)	1,081 (0.4)	281,871	41.6
2003	125,865 (42.0)	30,026 (10.0)	31,344 (10.5)	37,095 (12.4)	37,321 (12.5)	32,544 (10.9)	5,314 (1.8)	299,509	6.3
2004	126,609 (39.8)	35,366 (11.1)	34,009 (10.7)	36,440 (11.5)	46,693 (14.7)	34,247 (10.8)	4,680 (1.5)	318,045	6.2
2005	141,692 (41.8)	40,945 (12.1)	36,303 (10.7)	36,324 (10.7)	44,766 (13.2)	34,590 (10.2)	4,240 (1.3)	338,861	6.5
2006	143,249 (40.4)	41,516 (11.7)	37,611 (10.6)	37,046 (10.4)	46,819 (13.2)	40,515 (11.4)	8,113 (2.3)	354,869	4.7
2007	137,913 (36.8)	42,842 (11.4)	39,900 (10.7)	46,986 (12.6)	50,346 (13.4)	45,743 (12.2)	10,653 (2.8)	374,384	5.5
2008	145,531 (37.1)	48,798 (12.4)	41,067 (10.5)	45,265 (11.5)	48,662 (12.4)	48,281 (12.3)	14,717 (3.8)	392,323	4.8
2009	142,302 (35.1)	5,759 (14.2)	43,942 (10.8)	43,980 (10.8)	52,524 (12.9)	48,383 (11.9)	17,102 (4.2)	405,692	3.4
2010	143,379 (32.5)	58,613 (13.3)	53,255 (12.1)	51,207 (11.6)	57,692 (13.1)	52,248 (11.9)	24,473 (5.6)	440,868	8.7
2011	152,443 (33.0)	58,039 (12.6)	51,355 (11.1)	52,902 (11.4)	59,085 (12.6)	51,120 (11.1)	38,398 (8.3)	462,343	4.9
2012	148,515 (31.5)	60,136 (12.7)	50,035 (10.6)	54,126 (11.5)	61,079 (12.9)	54,891 (11.6)	43,014 (9.1)	471,795	2.0

Source: Reproduced from Korea Power Exchange (2013)

In the wholesale market in Korea, a generation company earns revenues through the sales of electricity and capacity, as mentioned in the above. Revenues from capacity sales are determined by the total capacity that the generation company owns, number of hours during which generators are ready to operate, and the unit price of capacity. Unit price of capacity is fixed at 7.17 KRW per KW since 2001. Thus the revenues from the sales of capacity increase in direct relation to the total capacity that is in operating condition. Except in the small number of cases of a few nuclear generators that had unplanned outage due to malfunctioning of generators, revenues from the sales of capacity are close to a linear function of the total capacity of the firm.

Annual revenue of a generation company that is not a subsidiary of KEPCO from the sale of electricity is determined by the electricity generated and the SMP in each of 8,776 hours[5]. Annual revenue of a generation company owned by KEPCO is determined by the electricity it sells and SMP in each hourly market as well as a discount factor called bojunggesoo, which lowers the price of the electricity a subsidiary of KEPCO receives compared to SMP that applies to the other firms. Bojunggesoo differs according to the fuel type and changes frequently. There is no rule or formula that determines bojunggesoo.

Bojunggesoo affects the average price of electricity a generators type receives each year. It should be noted that the average price of a generator type in a given year also depends on the SMPs and the amount of electricity generated during which the generator operates. Following [Table 2-4] contains information on the average price of electricity of generators of different types. It can be easily seen from the table that nuclear and coal fired power plants received prices for the electricity they sold that are far lower than the prices of electricity generated by other fuel types.

[Table 2-4 Average price of electricity of generators of different fuel types]

(Unit: hundred million KRW,%)

year	Nuclear energy	coal	domestic coal	LNG	oil	Pump and storage	hydro	Etc.	Total
2001	39.6	41.4	56.7	87.8	73.5	73.9	58.0	54.1	47.9
2002	39.5	42.4	48.7	75.6	71.0	83.6	54.5	46.5	47.2
2003	39.7	42.2	50.8	82.9	76.3	94.1	57.4	53.3	48.7
2004	39.5	41.9	52.2	77.9	81.6	108.2	62.0	58.3	49.2
2005	39.1	43.5	53.8	87.1	92.8	108.3	71.2	63.2	51.0
2006	38.1	38.4	54.6	103.0	116.7	136.8	84.0	82.2	53.3
2007	39.4	40.9	65.4	104.9	118.3	163.3	93.6	85.1	56.5
2008	39.0	51.2	117.5	143.7	194.4	196.8	134.3	128.6	68.3
2009	35.6	60.2	109.1	129.5	147.2	149.7	109.3	104.5	66.3
2010	39.6	60.8	110.0	128.1	184.6	202.6	133.5	104.5	73.1
2011	39.1	67.1	98.6	142.4	225.8	168.8	135.1	101.2	79.5
2012	39.5	66.2	103.8	168.1	253.0	213.9	111.3	164.3	90.2

5 In the Korean electricity market, there is a new market every hour.

Source: Reproduced from Korea Power Exchange (2013)

Bojunggesoo affects revenues earned by generators of each fuel type. Following [Table 2-5] contains the revenues of each generator type and their shares in the market. Share of nuclear was 13.3% in 2012 while its share in the electricity sold was 31.5%. Bojunggesoo naturally affects the revenues of generation companies that are subsidiaries of KEPCO gravely as shown by the following [Table 2-6]. KHNC's share of revenue from the sales of electricity in 2012 was 15.7% although its share in the total electricity sold in the same year was 31.5%.

[Table 2-5 Revenues earned by generators of each fuel type]

(Unit: hundred million KRW,%)

year (market share)	Nuclear energy	coal	domestic coal	LNG	oil	Pump and storage	hydro	Etc.	Total
2001	31,926 (33.5)	32,525 (34.1)	2,684 (2.8)	14,957 (15.7)	11,450 (12.0)	1,147 (1.2)	585 (0.6)	3 (0.0)	95,276
2002	45,357 (34.1)	45,965 (34.5)	2,969 (2.2)	23,734 (17.8)	12,309 (9.3)	1,729 (1.3)	965 (0.7)	22 (0.0)	133,049
2003	49,452 (33.9)	46,546 (31.9)	3,222 (2.2)	28,320 (19.4)	14,615 (10.0)	1,861 (1.3)	1,400 (1.0)	324 (0.2)	145,741
2004	49,456 (31.6)	49,243 (31.5)	2,737 (1.7)	37,000 (23.6)	14,553 (9.3)	1,652 (1.1)	1,477 (0.9)	449 (0.3)	156,568
2005	54,887 (31.8)	53,988 (31.2)	2,812 (1.6)	42,072 (24.3)	15,497 (9.0)	1,628 (0.9)	1,517 (0.9)	408 (0.2)	172,809
2006	54,190 (28.6)	49,689 (26.3)	2,830 (1.5)	58,758 (31.0)	18,072 (9.5)	2,381 (1.3)	2,608 (1.4)	716 (0.4)	189,245
2007	53,827 (25.4)	58,774 (27.8)	3,596 (1.7)	68,901 (32.6)	19,587 (9.3)	2,284 (1.1)	3,362 (1.6)	1,243 (0.6)	211,572
2008	56,291 (21.0)	82,051 (30.6)	7,436 (2.8)	93,644 (34.9)	17,430 (6.5)	4,880 (1.8)	4,039 (1.5)	2,228 (0.8)	267,999
2009	50,181 (18.6)	107,713 (40.0)	7,963 (3.0)	74,542 (27.7)	18,949 (7.0)	4,212 (1.6)	3,019 (1.1)	2,540 (0.9)	269,118
2010	56,207 (17.4)	111,480 (34.6)	8,417 (2.6)	109,074 (33.8)	21,860 (6.8)	5,621 (1.7)	4,840 (1.5)	4,755 (1.5)	322,243
2011	57,803 (15.7)	124,715 (33.9)	7,664 (2.1)	136,668 (37.2)	21,608 (5.9)	5,427 (1.5)	6,056 (1.6)	7,843 (2.1)	367,784
2012	56,736 (13.3)	122,298 (28.7)	8,324 (2.0)	176,799 (41.6)	36,740 (8.6)	7,774 (1.8)	6,847 (1.6)	9,878 (2.3)	425,397

Source: Reproduced from Korea Power Exchange (2013)

[Table 2-6 Revenues from the sales of electricity of generation companies]

(Unit: hundred million KRW,%)

year (market share)	KHNC	Namdong	Jungbu	Seobu	Nambu	Dongseo	Etc.	Total	Rate of increase from previous year
2001	32,430 (34.0)	11,181 (11.7)	10,167 (10.7)	14,654 (15.4)	12,985 (13.6)	13,730 (14.4)	129 (0.1)	95,276	-
2002	45,987 (34.6)	14,391 (10.8)	15,881 (11.9)	20,000 (15.0)	17,778 (13.4)	18,351 (13.8)	662 (0.5)	133,049	39.7
2003	50,274 (34.5)	14,462 (9.9)	17,708 (12.2)	21,114 (14.5)	20,343 (14.0)	18,564 (12.7)	3,276 (2.2)	145,741	9.5
2004	50,364 (32.2)	16,445 (10.5)	18,853 (12.0)	20,370 (13.0)	27,252 (17.4)	20,048 (12.8)	3,236 (2.1)	156,568	7.4
2005	55,830 (32.3)	19,977 (11.6)	22,216 (12.9)	22,023 (12.7)	28,258 (16.4)	21,151 (12.2)	3,354 (1.9)	172,809	10.4
2006	55,172 (29.2)	19,633 (10.4)	24,690 (13.0)	24,046 (12.7)	32,976 (17.4)	25,013 (13.2)	7,715 (4.1)	189,245	9.5
2007	55,053 (26.0)	21,402 (10.1)	27,930 (13.2)	30,880 (14.6)	37,212 (17.6)	28,615 (13.5)	10,481 (5.0)	211,572	11.8
2008	57,956 (21.6)	30,968 (11.6)	35,926 (13.4)	36,715 (13.7)	46,298 (17.3)	38,748 (14.5)	21,388 (8.0)	267,999	26.7
2009	51,457 (19.1)	37,188 (13.8)	37,032 (13.8)	37,949 (14.1)	46,077 (17.1)	38,165 (14.2)	21,249 (7.9)	269,118	0.4
2010	58,186 (18.1)	41,041 (12.7)	47,769 (14.8)	47,569 (14.8)	51,654 (16.0)	44,456 (13.8)	31,568 (9.8)	322,243	19.7
2011	65,227 (17.7)	43,083 (11.7)	49,948 (13.6)	51,864 (14.1)	58,978 (16.0)	46,976 (12.8)	51,708 (14.1)	367,784	14.1
2012	66,920 (15.7)	45,310 (10.7)	54,117 (12.7)	59,350 (14.0)	69,362 (16.3)	58,345 (13.7)	71,993 (16.9)	425,397	15.7

Source: Reproduced from Korea Power Exchange (2013)

Cost structure of nuclear generators is fundamentally different from those of other fuel type generators. Following [Table 2-7] summarizes the average cost structures of generators of each fuel type[6]. Average levelized fixed cost of the capacity of 1KW per hour of nuclear generators to be built in the near future was estimated to be KRW 43.3 for nuclear generators of the capacity of 1,000MW, KRW 38.2 for generators of the capacity of 1,400MW, and KRW 37.7 for generators of the capacity 1m500MW. Their fuel costs were estimated to be KRW 3.6, KRW 3.7, and KRW 3.7 respectively.

[Table 2-7 Estimated costs of generators of various fuel types included in the 6th plan for demand and supply of electricity]

[6] The numbers in the table have been obtained based on the assumptions that capacity factor of all generators except pump and storage is 90%, capacity factor of pump and storage is 20%, life span of each generator is 40 years for nuclear, 55 years for pump and storage, and 30 years for the rest. The price used is 2012 price. Discount factor of 6% and exchanges rate of KRW 1,150 per USD were also used.

		Fixed Costs			Variable Costs	Total Costs of Generation
		Construction Costs	O&M Costs	Total Fixed Costs	Fuel Costs	
		KRW 1,000/kW	KRW 1,000/kW month	KRW/kWh	KRW/Gcal	KRW/kWh
Nuclear (PWR)	1,000 MW class	2,590	11.89	43.3	1,490	46.9
	1,400 MW class	2,365	10.17	38.2		41.9
	1,500 MW class	2,360	9.85	37.7		41.4
Coal	500 MW class	1,454	4.08	21.4	20,516	65.1
	800 MW class	1,436	3.55	20.2		64.6
	1,000 MW class	1,419	3.21	19.5		61.9
Oil	40 MW class	2,462	12.34	45.2	74,165	199.6
	100 MW class	2,276	9.76	40.2		216.8
Combined Cycle	400 MW class	1,148	3.71	17.0	67,145	125.2
	800 MW class	955	2.71	13.6		117.8
Pump & Storage	300 MW class	911	2.30	53.7	-	-

Source: Korea Power Exchange

On the other hand, average levelized fixed cost of a combined cycle generator was estimated to be KRW 17 and LRW 13.6 for generators of the capacity of 400MW and 800MW respectively, and average fuel cost was estimated to be KRW 108.2 and KRW 104.2 per KWh respectively. The levelized per unit fixed costs of nuclear generators are in the rage of 2 ~ 3 times the levelized per unit fixed costs of combined cycle generators. But per KWh fuel costs of nuclear generators are around 3.3% of the fuel costs of combined cycle generators.

Levelized per unit total cost of nuclear generators is less than 50% of combined cycle generators and less than 2/3 of coal-fired generators. Thus nuclear generators are much more efficient in terms of the cost when we do not consider the costs of treating and storing radioactive wastes, decommissioning, and decontamination. These costs have not been estimated using a reliable method yet, and there is a huge uncertainty as to their true value.

The true cost of using nuclear generation also includes the cost from accidents. Thus, the expected costs of nuclear generation should also the expected cost of accidents, which depends on the probability of various accidents and the costs to be incurred by the whole country when they occur. This cost has never been properly estimated either.

It is possible that the sum of these expected costs can be higher than the cost advantage of nuclear generators. However, it seems that policy makers in most countries believe that the sum of the expected costs of treating and storing radioactive wastes, decommissioning, decontamination, and accidents are significantly lower than the cost advantage of nuclear power plants over other fuel type generators.

3. Investment decisions, market rules, and profitability of nuclear generators

Who can operate a nuclear power plant in Korea? The Act on the Electricity Business requires that anyone who wants to build or operate a nuclear power plant must obtain an approval from the government, but does not specify the conditions the government should use in granting a license to build or operate a nuclear power plant. In practice, the government has the power to make decisions on who will build or own or operate nuclear power plants and has been using the power to allow only one firm to build, own, and operate nuclear power plants. Before restructuring, the Old KEPCO was the only firm that was allowed to own and operate a nuclear power plants. After restructuring, KHNC has been the only firm allowed to build, won, or operate a nuclear power plant.

KHNC and the government jointly make decisions on investment and retirement of nuclear power plants. Estimation of the optimal generation mix results in the proportion of nuclear generators of around 90% with the rest consisting of combined cycle and hydro, reflecting the vast cost advantage of nuclear[7]. However, the government considers various factors including political opposition to a big increase in nuclear generation capacity and the supply of labor

[7] Estimation of optimal generation mix is regularly conducted by Korea Power Exchange using software called WASP developed by IAEA. Although it does not publish the details of the estimation process or results, it acknowledges unofficially that the estimation using WASP results in the proportion of nuclear at around 90% of the total capacity.

with necessary expertise and training. Little detail is known about how the government and KHNC make decision on the investment in nuclear capacity. The government simply fixes and announces its plan on investment every two years as a part of the Plan on Demand and Supply. According to the most recent plan, the government will allow KHNC to build 11 new nuclear generators with the combined capacity of 15,200MW in the next 10 years or so.

The plan clearly implies that nuclear power plants will earn huge supra normal profits if they sell electricity in the market according to the SMP and the capacity price. The supra normal profit of nuclear generators is difficult to justify as it is a result of the policy of the government that puts a ceiling on the total nuclear capacity. The policy that the government is using, and is planning to use in the future too, to control the profitability of nuclear generators is bojunggesoo.

But bojunggesoo has the following problems.

First, it is extremely arbitrary. Bojunggesoo applies to all types of generators owned by KEPCO including combined cycle generators. There simply does not exist a criterion that is publicly available that the Korean government uses in determining bojunggesoo for various types of generators.

Second, there is a possibility that the one of the objectives behind Korean government's use of bounggesoo is to make the ex post accounting profitability of generation companies owned by KEPCO similar to each other. If this is indeed the case, it will lower the incentives of managers of KHNC to build and operate nuclear generators efficiently[8].

Third, even if bojunggesoo is used as a measure to maintain the profitability of nuclear generators at a reasonable level, it will lead to the same distortion in incentives that the conventional rate of return regulation mechanism suffers from. Consequently, executives and employees of KHNC will have little incentive to build and operate nuclear power plants efficiently.

In short, bojunggesoo will lead to inefficiency in investment, construction, and operation of

[8] Managers of other generation companies owned by KEPCO will have the same distortion in their incentives.

nuclear power plants.

What alternatives does the Korean government have? It is clear that any solution to the problem should be compatible with effective competition in the wholesale market and should be a part of the market rules. In other words, a reasonable solution to the problem of designing the pricing mechanism for the electricity and capacity of nuclear generators requires redesigning of the market rules from their current form. We propose the following change in the market rules[9]:

- Eliminate the capacity price currently in use for nuclear generators.
- Set price of electricity = SMP regardless of the fuel type of generators at all times.
- Elimination of bojunggesoo.
- Force KHNC and KEPCO to sign a long term bilateral contract for each of the nuclear generators it will build in the future that specifies a strike price for the electricity KHNC sells to KEPCO. The strike price is time-dependent and is a function of the demand function, fuel prices, and the generation mix in each hourly market in the future. If SMP exceeds the strike price, KHNC pays (SMP – strike price) for each unit of electricity it sells. KEPCO pays KHNC (strike price – SMP) for each unit of electricity traded. The strike price is set in such a way that the discounted expected sum of the profits from the sales of electricity equals the sum of the discounted expected value of investment and all costs other than the fuel costs[10]. Alternatively, the government may allow KHNC to sell a small

[9] We assume that the government will not allow the wholesale market price of electricity to go above the SMP determined by the Cost Based Pool (CBP) rules currently in use, which essentially implies that we restrict attention to the market rules in which the price of electricity is the same as SMP.

[10] This form of bilateral contracts that are forced by the government on generation companies and retailers in the early stage of restructuring are generally called vesting contracts and have been used in other countries, including U.K., Australia, and Singapore. Strangely, the academic literature on vesting contract is almost void. Vesting contracts that are available in Korea are only the proposed drafts prepared by foreign consulting firms in the late 1990s and early 2000s for KEPCO and the Korean government. KEPCO and the government did not implement the vesting contracts drafted by foreign consultants. The scheme we described here for nuclear generators is similar to the vesting contract proposed by consultants in the early 2000s for combined cycle and oil fired generators.

percentage of electricity generated by its nuclear power plants to the spot market instead of selling 100% of the electricity generated by its nuclear power plants.

At the same time, the price of carbon emission must be determined appropriately and be charged to coal, gas, and oil fired generators, and entry barriers to non-nuclear generators should be removed. Removal of entry barriers will require a fundamental revision of the part of the Electricity Business Act and the Act on the Promotion of Development of Generation Sources on licensing of new generators and the Plan for Demand and Supply.

Full description of the optimal market rules that should replace the current market rules is beyond the scope of this paper. But, we propose the following changes in the market rules as well.

- Eliminate the capacity price currently in use for all generators as it has no firm economic ground.
- Introduce a capacity price for each generator that reflects the construction cost and the expected O&M costs which has the property that it is essentially a one shot payment to paid at the time of the start of operation. Payment period can be flexible but should not be too long[11].

4. Development of new reactors and incentives of firms in adopting new reactors

The long-term market for nuclear generation is complex. Vendors are constantly working to develop better reactors that are safer and more economic. Over time, new generation of reactors replace the old generation of reactors. Most nuclear reactors used for power generation around the world today are generation 2 reactors. There are 12 major vendors around the world that develop, manufacture, and sell nuclear power plants. They are Toshiba/Westinghouse, AREVA, GE Energy, Atomenergoprom, AECL, Mitsubishi Heavy Industry, NPC of India, Hitachi, Skoda Praha, Doosan Heavy Industry, Babcock & Wilcox,

[11] Spain appears to have used this form of capacity price.

and CNNC[12].

Development of generation 3 reactors, currently sold in the world market for new reactors, involved substantial risks as it required the investment of large sums of money on R&D and construction of new reactors under a big uncertainty about their performance, ultimate costs, and demand. In Korea, KEPCO E&C and Doosan Heavy carried out most of the development activities of generation 3 reactors. Once they completed the development, KHNC purchased reactors from them and also pay for the construction of reactors and the rest of the power plants for generating electricity in the future.

In other words, it is KEPCO E&C and Doosan on the vendor side and KHNC on the generation company side that make key decisions on the development, construction, and deployment of next generation reactors in the domestic market. However, most of the risks involved in development, construction, and deployment of new reactors are borne by KEPCO, which owns 74.5% of KEPCO E&C and 100% of KHNC. KEPCO is also exposed to the risks of having to purchase electricity at higher prices in the wholesale market if new nuclear power plants function less efficiently than had been anticipated or their construction is delayed.

Irregular procurement of parts and equipment used to build and operate nuclear power plants by KHNC also costs KEPCO dearly in four different ways.

First, higher prices that KHNC paid led to the commensurate decrease in the value of KHNC KEPCO owns.

Second, malfunctioning of faulty parts and equipment and poor services KHNC purchased from its suppliers resulted in frequent unplanned outages of nuclear power plants, which led to a significant decrease in the revenue and profit of KHNC and its firm value.

Third, frequent and prolonged interruptions of services by KHNC's nuclear generators, that are due ultimately to its irregular procurement practices, resulted in a sharp increase in SMP in the wholesale market for significantly long hours. As a result, KEPCO was forced to pay

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[12] For detailed information on the performance of major vendors and the market share distribution, see OECD-NEA(2008).

significantly larger amounts of money for the electricity generated.

Fourth, reduced supply of power resulting from unplanned outages of some nuclear reactors owned by KHNC forced KEPCO to pay significantly larger amounts of money for demand management in order to prevent large scale black-outs.

The above arguments show that the authority and risks involved in investment in nuclear capacity are allocated sub-optimally. This inefficiency will persist unless the authority and the risks are re-allocated in such a way that the party that is exposed to a risky investment is given the authority to make decisions on investment.

Vendors and developers of alternative nuclear technologies around the world also develop nuclear reactors that are more advanced than or significantly different from generation III reactors. Many of the 12 vendors that have been selling their reactors are expected to develop and commercialize generation 4 reactors in the future[13]. In Korea, KEPCO E&C and Doosan are expected to play a key role in the development of generation 4 reactors. There is another group of next generation reactors, generally called small modular reactors, which are different from the commercial reactors that have been used and generation 4 reactors that are being developed.

Small rectors have been developed by Korea Atomic Energy Research Institute (KAERI), a research institute run by the Ministry of Future and Creation. KAERI is independent of KEPCO, its subsidiaries, or Doosan. KAERI completed the development of a small reactor called SMART a few years ago and obtained a basic license from the Korean government to build and operate a SMART reactor KAERI claims that its SMART reactor significantly reduces the risks of serious accidents and produces significantly less highly radioactive wastes and wants to build a power plants equipped with its SMART reactor in Korea and to sell electricity it generates in the wholesale market. It also has a plan to export SMART reactors to other countries once it successfully builds and operates its first SMART reactor in Korea. KAERI's plan is interesting in that SMART is a significantly different reactor from conventional generation III reactors.

[13] IAEA forecasts that generation 4 reactors will begin construction after 2030.

KAERI's plan is also interesting in that it allows a firm other than KHNC to develops, builds, and operates a nuclear power plant in Korea. For KAERI to build and operate its SMART power plant, it will need to find investors first. Whether KAERI succeeds in attracting the money needed finance the project depends crucially on the costs of construction and operation as well as the market rules that apply to KAERI's nuclear power plant. One reasonable way to make decisions on the investment in SMART reactors is to let the market decide. Then, whether KAERI will succeed in attracting the needed capital will depend crucially on the market rules that apply to the SMART power plant, which determines the operating profits of the power plant.

There arises the question of whether the government should apply the same bilateral contract for KHNC and KEPCO that we proposed in the previous section to the SMART power plant. Doing so is likely to lead to a loss of large amounts of money for investors who participated in the SMART power plant as per MW construction cost of the first SMART generator is significantly higher than that of a typical generation III nuclear generator while the operating cost will be similar according to the estimation conducted by KAERI. Thus, subjecting the SMART generator to the same market rules and bilateral contracts that apply to KHNC's nuclear generators will make it very difficult if not impossible for KAERI to raise capital needed to finance its SMART generator.

There is no plausible reason to subject SMART power plant to the same bilateral contracts that KHNC's conventional nuclear generators are subject to as its cost structure is significantly different from those of conventional nuclear generators. If SMART is indeed safer than conventional nuclear power plants and turns out to be significantly more acceptable politically, it would be plausible to subject it to the market rules that apply to non-nuclear generators. On the other hand, if SMART generators entail risks that are similar to conventional nuclear power plants, they are just more inefficient nuclear generators, and it would be difficult to apply different contracts and market rules to them from the ones that apply to conventional nuclear generators[14].

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[14] If SMART generators turn out to be unprofitable even if they are subject to the market rules that apply to non-nuclear generators in our proposal, they will probably not be built without additional subsidies from the government. Under what circumstance should the government provide additional subsidies and the form and

5. Conclusion

In this paper, we analyzed the performance of nuclear generators and the effects of the market rules on the financial performance of the nuclear generators in Korea and found that the current market rules that apply to nuclear reactors are likely to induce an inefficient outcome. We proposed an alternative set of rules for nuclear power plants that are superior to the current rules in that it gives KHNC and its employees a stronger incentive for efficiency in operations. We also analyzed the incentives of major players that make decisions on the development and construction part of the nuclear power industry. We found that current regime does not assign authorities and risks properly and is likely to lead to inefficiency in development, procurement, and construction of nuclear power plants and argued for reallocation of authorities and risks in such a way that the parties that are exposed to the risks are given the authorities to control them. Lastly, we briefly discussed the key issues in investment in small modular reactors in Korea and the market rules that are appropriate to apply to SMART generators.

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magnitude of the subsidies will depend on the industrial policy objectives of the government. We will not discuss it further in this paper as it clearly goes beyond the scope of this paper.

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