

## **Simulation of Power Plant Construction in Competitive Korean Electricity Market**

**Namsung Ahn, Sungchul Huh**

Korea Electric Power Research Institute

103-16 Munji-dong, Yusong-gu, Taejon 305-380, Korea

### **Abstract**

This paper describes the forecast of power plant construction in competitive Korean electricity market. In Korea, KEPCO (Korea Electric Power Corporation, fully controlled by government) was responsible for from the production of the electricity to the sale of electricity to customer. However, the generation part is separated from KEPCO and six generation companies were established for whole sale competition from April 1st, 2001. The generation companies consist of five fossil power companies and one nuclear power company. Fossil power companies are schedule to be sold to private companies including foreign investors. Nuclear power company is owned by government. The competition in generation market will start from 2003. ISO (Independence System Operator) will purchase the electricity from the power exchange market. The market price is determined by the SMP (System Marginal Price) which is decided by the balance between demand and supply of electricity in power exchange market. Under this uncertain circumstance, the energy policy planners are interested to the construction of the power plant in the future. These interests are accelerated due to the recent shortage of electricity supply in California. In the competitive market, investors are no longer interested in the investment for the capital intensive, long lead time generating technologies. Large nuclear and coal plants were no longer the top choices. Instead, investors in the competitive market are interested in smaller, more efficient, cheaper, cleaner technologies such as CCGT (Combined Cycle Gas Turbine). Electricity is treated as commodity in the competitive market. The investor's behavior in the commodity market shows that the new investment decision is made when the market price exceeds the sum of capital cost and variable cost of the new facility and the existing facility utilization depends on the marginal cost of the facility. This investor's behavior can be applied to the new investments for the power plant. Under these postulations, there is the potential for power plant construction to appear in waves causing alternating periods of over and under supply of electricity like commodity production or real estate construction. A computer model was developed to study the possibility that construction will appear in waves of boom and bust in Korean electricity market. This model was constructed using System Dynamics method pioneered by Forrester (MIT, 1961) and explained in recent text by Sternman (Business Dynamics, MIT, 2000) and the recent

work by Andrew Ford ( Energy Policy, 1999). This model was designed based on the Energy Policy results (Ford, 1999) with parameters for loads and resources in Korea. This Korea Market Model was developed and tested in a small scale project to demonstrate the usefulness of the System Dynamics approach. Korea electricity market is isolated and not allowed to import electricity from outsiders. In this model, the base load such as nuclear and large coal power plant are assumed to be user specified investment and only CCGT is selected for new investment by investors in the market. This model may be used to learn if government investment in new nuclear plants could compensate for the unstable actions of private developers. This model can be used to test the policy focused on the role of nuclear investments over time. This model also can be used to test whether the future power plant construction can meet the government targets for the mix of generating resources and to test whether to maintain stable price in the spot market.

## **1. Background**

Construction cycles have been observed in a various industries including manufacturing, real estate construction and commodity production (1999, Sternman). The cycles have not been as prominent in the regulated electric industry because of the government owned utility's clear obligation to build the power plants needed to keep pace with demand. However, the commencement of deregulation in the generation market drives the fundamental change in the traditional rules. In the competitive market, the utility has no obligation to serve any or all of the demand. The new investment for the future is determined by the market price decided based on the balance between supply and demand.

In Korea, KEPCO (Korea Electric Power Corporation) has been responsible for generation, transmission, distribution, and sale to customer. KEPCO is controlled by government and has had full responsibility for the supply of electricity to keep pace with demand. However, according to the privatization policy of government, generation part is separated from KEPCO from this April 1<sup>st</sup>, 2001. Six generation companies (five fossil power generation companies and one nuclear company) will be established. Five fossil power generation companies are scheduled to be sold to private companies including foreign investors.

Under this uncertain circumstance, the energy policy planners are interested to the construction of the power plant in the future. These interests are accelerated due to the recent shortage of electricity supply in California. They are worrying the possibility of the boom and bust in the construction of power plants in Korea after deregulation. In the competitive market, investors are no longer interested in the investment for the capital intensive, long lead time generating technologies. Large nuclear and coal plants were no longer the top choices. Instead, investors in the competitive market are interested in smaller, more efficient, cheaper, cleaner technologies such as CCGT (Combined Cycle Gas Turbine). After the shortage of electricity in California, many energy planners in Korea starts to suspect the market

power which has been thought to be able to supply the electricity. They begin to worry the market price stability in the future. They also worry about the possibility of stable construction of power plants when CCGTs are the only option in the market in Korea. Under these circumstances, it is very important to investigate how much large scale nuclear or coal plants can contribute to the stable supply in Korea.

A computer model was developed to study the possibility that construction will appear in waves of boom and bust in Korean electricity market. This model was constructed using System Dynamics method pioneered by Forrester (MIT, 1961) and explained in recent text by Sternman (Business Dynamics, MIT, 2000) and the recent work by Andrew Ford (Energy Policy, 1999). This model was designed based on the Energy Policy results (Ford, 1999) with parameters for loads and resources in Korea. This Korea Market Model was developed and tested in a small scale project to demonstrate the usefulness of the System Dynamics approach. Section 2 describes a model and postulations designed to simulate the potential for cycle behavior in the electricity market in Korea. The model simulates the key feedback mechanisms that give rise to construction cycles. Section 3 represents the simulation results which reveal that cyclical behavior could emerge under wide assumptions on demand. Section 3 also describes the simulation results showing the contribution of nuclear to the stabilization of the market price as a sweeping producer. This paper concludes by adding some recommendations for energy policy in order to stabilize the market price using nuclear and coal power plant construction.

## **2. Model Description**

### **2.1 Feedback Mechanism**

The focus of this paper is the stability of construction and power exchange price over time, so it is important to appreciate the principal feedback mechanisms in the model. Figure 1 shows the two balancing loops which will dominate the simulated system over time. The existing plant loop represents the rapid adjustments in generation from existing power plants responding to changes in the power exchange price. The existing imported coal, oil, domestic coal and gas plants are included in this category. This loop acts without delay to keep the supply and demand on the power exchange in balance. This loop does its job as long as there is sufficient generating capacity. The existing plant compares the power exchange price with its variable cost. The variable cost of existing plant is composed of the variable O&M cost and fuel cost. Among the existing plants, only plants whose variable cost does lower than the power exchange price can be selected for operation.

The new investment loop in Figure 1 describes how the new investment is decided in the market. Investors look beyond today's power exchange price in judging profitability. Investors observe the power exchange price trend for some observation period in order to determine the future power exchange price. The increase in power exchange price leads to an increase in investor's forecast of profitability

and an increase in the number of CCGTs starting process and the number of CCGT starting construction. After the construction period of CCGTs, the completed CCGTs comes on line and supply the electricity to the market. The increase in capacity reduce the demand imposed on the power exchange market and lead to a downward adjustment in the power exchange price.

## 2.2 Supply of Electricity in Korean Market

The data released by KEPCO indicates that the total capacity of electricity supply in Korea is 47,895MW at year 2,000. After considering the availability, the supply capability is reduced to 38,808 as shown in Table 1: These data are calculated based on “Status of Power Plants in Korea at 2,000”.

## 2.3 Demand for Electricity

The demand for electricity in Korea is set to 32,000 aMW at the start of simulation. The simulation starts from 2000 year. The user specifies the demand growth rate over time. This study adopts the standard assumption of 5%/year, the expected growth rate by the energy planners. Historical growth rates in Korea have been as high as 10%/year. The growth rate is assumed to apply year after year. The model represents the electricity demand as the energy required over the entire year after the impact of demand side management. Four growth rates (3%, 5%, 7%, 10%) are used for sensitivity study for various demand growth rates. The interviews with energy planners reveal that the demand in Korea will increase continuously regardless of the feedback of price to demand. This leads us to ignore the link from the market price to demand.

**Table 1: Status of Power plant Capacity at year 2000**

Fuel	Total Capacity (MW)	Availability	Possible Supply Capacity(MW)
Hydro	1,548	0.9	1,393
Pump Storage	1,600	0.22	347
Nuclear	13,716	0.8	10,973
Imported Coal	12,740	0.8	10,192
Domestic Coal	1,291	0.8	1,033
Oil	4,310	0.8	3,448
LNG	12,690	0.9	11,421
<b>Total</b>	<b>47,895</b>		<b>38,808</b>

## 2.4 Must Run Units: Cogeneration, Hydro, Nuclear

Cogeneration and hydro generation are assumed to be “Must Run Units”. The cogeneration capacity is set to 4609 MW @61% availability, so we expect 2,811 aMW of generation. Hydro

generation is set at 3,148MW. Nuclear power plants are also treated as “Must Run Units”. The simulation begins with 13,715 MW @ 80% availability, so the initial nuclear generation is 10,972 aMW. Nuclear generating capacity increases during the simulation. One flow keeps track of nuclear capacity that is under construction at the start of simulation. This flow uses PULSE functions in VENSIM to bring additional units into operation according to an existing government plan. For case one, only the additional nuclear units under construction now are considered. For case two, the planned nuclear units until 2011 year including KNGR 1&2 are considered in this model.

## **2.5 Existing High Cost Generation**

The final categories for existing generation are coal, oil, and LNG generators. All coal and gas generation is controlled by the price established by the power exchange. We assume that the owners of coal and gas units bid their energy at variable costs, and the PX operator finds the PX price to clear the market. The model calculates the fraction of coal capacity in operation by finding the heat rate of a coal fired unit that is on the margin.

Coal units are broken down into plants that burn imported coal and plants that burn domestic coal. With 12,740MW of capacity @80% availability, we would have 10,192 aMW of generation at the start of simulation. The domestic coal units burn coal price at 2.83\$ per MBTU. The domestic coal is 2.36 times more expensive than imported coal. There is 1,291 MW of capacity @80% for a maximum generation of 1,033 aMW. The use of domestic coal plant was constructed to protect domestic coal industry. Oil fired units has 4,570MW of capacity @ 80% capacity factor. The maximum generation would be 3,656 aMW. Older gas burning units are the most expensive units on the system due to the high price of gas and high heat rates. The market looks to oil and gas unit to deliver 3,844 aMW and the oil fired units would deliver 3,656 aMW at the start of simulation.

## **2.6 The Px Price**

The electricity demand imposed on the Px is found by subtracting the “Must Run” generation from the total demand in Korea. The model searches for the Px price that will bring forth the needed generation through a simple heuristic algorithm. The heuristic approach mimics the Px price resulting from an auction, but it avoids the type of simultaneous calculations performed by Px manager. The Px price is adjusted up and down over time to clear the market. The model does not keep track of daily or seasonal variations in demand, nor does it simulate the hourly and seasonal adjustments in the Px price. It means we use the annual average price as a single number to summarize a complex distribution of prices over the many hours in a year.

## 2.7 Investors' behavior

The results of interview with utility planners and energy policy professors reveal that investors will look beyond today's Px price in judging profitability. In this model, we assume that investors observe the Px price over time to judge the overall trend. The observed growth rate is then trended into the future to estimate the Px price that could apply when a new unit would start operation. The investors' "forecasting horizon" is taken as the sum of the permitting interval, the construction interval to look into the first few year's of the plant's operating life. Investors forecast the future Px price when a new CCGT would begin operation. If the Px price exceeds the total levelized cost of CCGT, investors proceed with applications for the construction permits. The Px price is set at the cost of the most expensive generating unit needed to meet the total demand. If the short of electricity supply occurs, the pool operator is forced to impose a price cap to limit the price. Under these circumstances, the model imposes a "Circuit Breaker" mechanism to interrupt the normal operations.

## 2.8 Investment in new CCGTs

Investors may select from technologies ranging from small scale distributed technologies to large-scale coal and nuclear plants. However, the large-scale technologies are unlikely to draw investors' interest and distributed generation may not be able to complete. Various studies about the investors' behavior in investment reveal that investors will probably be drawn to combined cycle cogeneration or combined cycle, depending on the price of gas. This model assumed that CCGT will be constructed based on investors' forecasts of the future Px price. If investors look into the future and see a price exceeding total levelized cost, they will apply for construction permit. It is assumed that investors will not apply for a construction permit until they see a profitable Px price in the future. This model assumes that investors are continuously monitoring the Px price. If they believe that profitability has dropped during the 12 months permitting period, they cancel the project and there is no construction. But CCGT still appear profitable, investors will initiate construction. This paper focuses on CCGTs with the following attributes based on a California Energy Commission study:

Capital Cost: 600\$/Kw

Fixed Charging Rate: 14.5%

Fixed O&M Cost: 10\$/Kwh per Year

Availability Factor: 0.9

Heat Rate: 6,800 BTU/Kwh

Variable O&M Cost: 2\$/Kwh per Year

Fuel Cost: 4.14\$/MBTU

**Total Levelized Cost: 42.5\$/Mwh ( 47 Won/Kwh)**

The total levelized cost will increase over time with increases in the price of natural gas. Since the variable cost determined by the natural gas cost reaches almost 60-70% of total levelized cost of CCGT, the price of natural gas contributes to the determination of Px price.

### 3. Simulation Results

The purpose of this simulation is to see the stability of electricity supply in case of deregulation. Market is responsible for the supply of electricity in deregulation. We assume that the choice of investors is limited to CCGT only. When market price exceeds the total levelized cost of CCGT, investors decide new investments. This paper focuses on the possibility of boom and bust cycle in the construction of power plant when the construction is fully dependent on the market mechanism and focuses on the role of nuclear and large-scale coal plants for stabilizing the market price. The simulations were conducted for two cases: Case 1 is the case that all the plants under construction currently including nuclear and large-scale coal plants come on line. The rest is provided by market mechanism. Case 2 is the case that all the planned nuclear and coal plants until year 2011 are assumed to come on line. The market provides the rest. Nuclear and coal generating capacity increases during simulation. One flow keeps track of nuclear capacity that is under construction at the start of simulation. This flow uses PULSE functions in VENSIM to bring additional units into operation in the 2002 (YK5), 2004 (YK6), 2005 (UC5&6) years of simulation for Case 1. For Case 2, the model user specifies additional nuclear construction. The flow of new nuclear starts uses PULSE functions in the same manner as Case 1 to start construction of new units in the 2008(New Kori 1), 2009(New Kori 2), 2010(New Kori 3 and 4), 2011(KNGR1), and 2012(KNGR2).

Figure 2 shows a customized graph of the Px price, Reserved Margin, and CCGT On-Line in case of 5% growth rate in demand for Case 1. As expected, the Px price exhibits cyclical behavior. The initial increase in the Px price results from the misbalance between supply and demand. When the demand increases 5% in year 2001, the new installed power plant can not meet this growth rate. This leads to the increase in the use of expensive LNG plants which has high marginal cost and results in the increase in the Px price. When the Px price increase higher than the total levelized cost of CCGT, the investors start to construct new CCGTs. When the construction of power plants is completed and come to on-line, the supply exceeds the demand and the Px price drops. This boom and bust cycle is repeated due to the feedback of system, time delay in construction. The sensitivity study for the various grow rates in demand is shown in Figure 3. The result reveals that when the growth rate is less than 5%, the market can provide enough new investments. However, the shortage of supply is expected in case of 7% growth rate. When the growth rate is 10%, we can expect the shortage of electricity supply with in 4-5 years. This shows the same problem as California. For case 2, nuclear and large-scale coal plants until 2012 is added as user input. In this case, we can see the same problems for the higher growth rate

than 7% as shown in Figure 4 even though the amplitude of cycle until 2012 lowers than Case1. From this result, we can conclude that the continuous addition of nuclear and coal is necessary in order to mitigate the boom and bust cyclical problems.

#### **4. Conclusions**

From the simulation results, we can see that the power plant construction in the competitive market exhibits boom and bust cycle in the same way as real estate construction or commodity production. The results also reveal that when the growth rate in demand is higher than 7%, the shortage of supply is expected under the competitive market like California. Specifically, when the growth rate is 10%, the shortage of supply comes within 4-5 years in case of Case 1. For Case 2, the same results were driven and the shortage is expected with a time delay. The result of this simulation recommends that nuclear plants and large-scale coal plants be added by government or KEPCO in order to stabilize the market.

#### **References**

1. Cycles in Competitive Electricity Market : a Simulation Study of the Western United States, Andrew Ford, Energy Policy 27(1999)
2. Understanding Strategic Decisions in De-Regulated Markets: Accelerate Learning through Simulation, Shayne Gary, London Business School(1988)
3. Business Dynamics: Systems Thinking and Modeling Complex World, Sternman, MIT
4. California Energy Commissions Scenarios Report, CEC(2000)
5. 2000 ( )
6. 1999 가 ( )



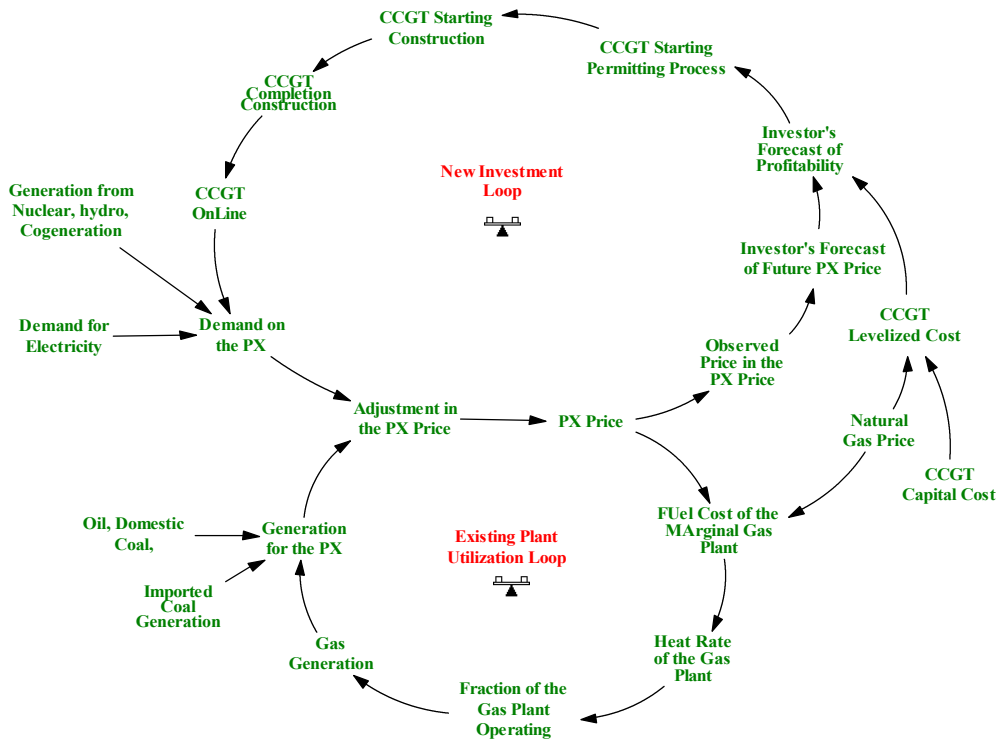


Figure 1. Two Balancing Loops which determine the Stability of the PX price

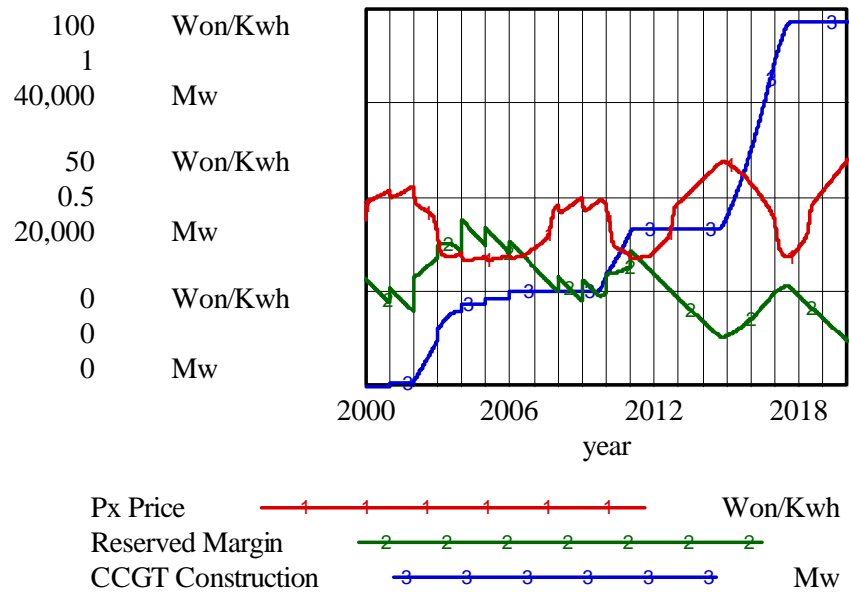


Figure 2. Oscillation in Px Price, Reserved Margin, and CCGT Construction for 5% Growth Rate in Demand

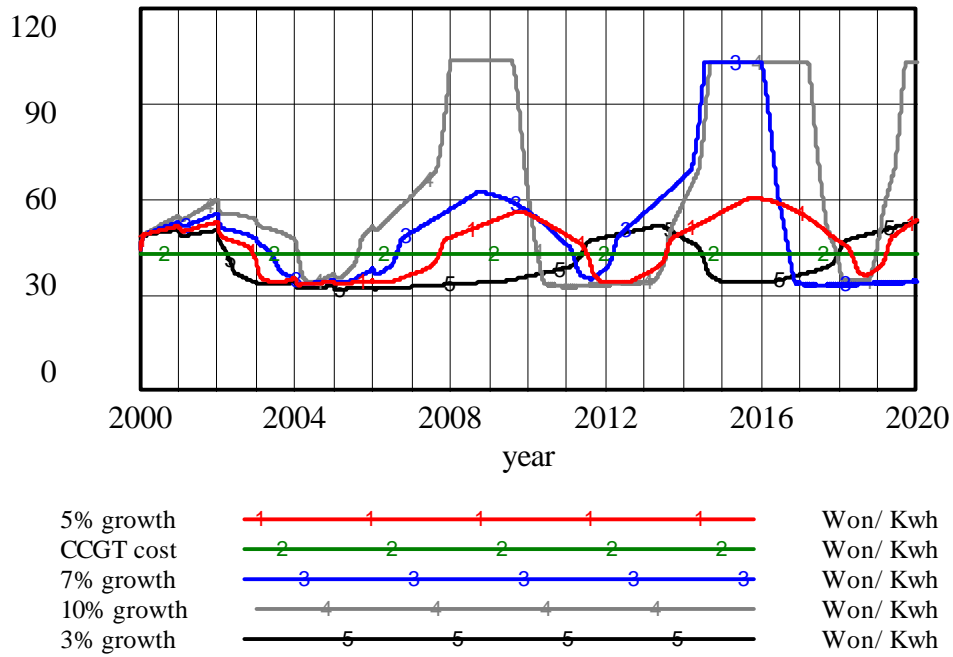


Figure 3. Px Price for the Different Growth Rate in Demand for Case 1

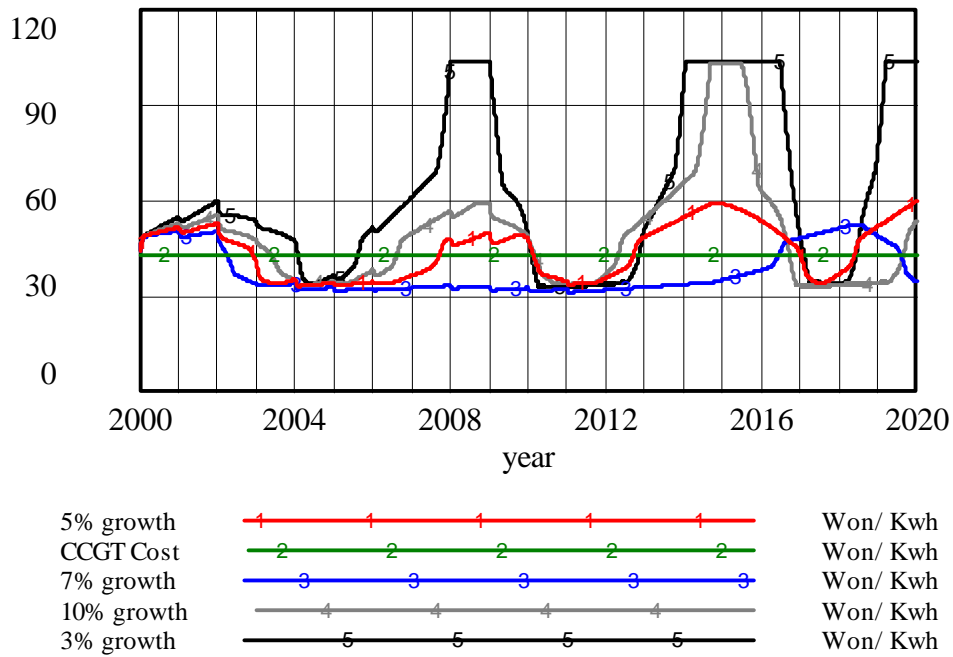


Figure 4. Px Price for the Different Growth Rate in Demand for Case 2