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A STUDY ON END-OF-PIPE COSTS IN THE MANUFACTURING SECTOR IN A DEVELOPING ECONOMY: A KOREAN CASE

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ABSTRACT

The relationship between industrial development and the environment still seems to be negative in a developing economy. Important features in the relationship are the generation of pollutants and relerant control activities. The reactive control activities are related to regulations and executive policies followed by burdensome costs of private manufacturing firms. The firms consequently try to lessen the burden and adopt an environment-friendly strategy, which is still normative in a developing region. A simple system dynamics model is applied for understanding the underlying patterns of feedback and dynamics regarding such activities in Korea.

Simulation results suggest that stringent regulations amplify the clean-up cost and the demand/price in the pollution-control sector, affect the level of the pollution-control technology and as a result, bring the burden of the cost of end-of-pipe control activities to the manufacturing sector in a short term, which lead to the development and diffusion of clean technology in the manufacturing sector and ultimately lead to an overshoot and collapse structure of the pollution-control sector. Thus the government needs to provide adequate industrial policies such as technology-push strategies for the pollution-control sector as well as the manufacturing sector.

1. INTRODUCTION

Not so long ago that pollution and degradation of the environment made people legislate regulations against them. Policy designers tend to seek an attempt at strategies toward sustainable development [9, 17]. One of them in Korea, as a strict code of practice for environmental conservation, is the standard on pollution emission that follows the nationwide environmental standard that has been revised several times since the 1980s [15]. Regulations have been amended within a relatively short period in most developing countries as compared with developed ones [29].

Regulations aim at economic incentives on reducing the amount of pollutants generated in such a way that environmental policies related to regulations seek an end-of-pipe solution first and gradually move to the in-the-pipe solution that makes products and production processes pollute less. Pollution abatement activities, therefore, play a significant role in an economic unit in that the pollution-control sector in an economy meets an increasing demand for various pollution-control equipment and services. The sector could sustain a relatively high growth rate of about 30% over the last decade [4, 16].

On the other hand, this outstanding growth of the sector increases the burden of the clean-up costs for the manufacturing sector. Most manufacturing firms should pay annually increasing costs of clean-up in response to regulations. The rapidly reinforced regulations make the clean-up costs of the manufacturing sector unstable and discontinuous. There is always excess demand and lack of supply capacity in the market of pollution-control equipment and services in an emerging stage [10]. A sudden technology leapfrogging might be needed to solve this problem in the manufacturing sector. Government planning or intervention on the supply of technology, technical manpower and other important factors is also expected in such an imperfect market situation. This is so critical in the sense of sustainable development that we should know whether we can meet technological attainability and economic alternatives to reduction of pollution generation and abatement of pollution emission [19].

The following questions can be raised naturally in this context.

- How long can the pollution-control sector keep up the high growth in the future as much as it has enjoyed? In other words, how will the demand of pollution-control sector behave in the future?
- What kinds of policies can be made to overcome the pollution-control market discrepancy between excess demand and lack of supply capacity?

The objective of this paper is to answer the above questions through examining the underlying patterns of the pollution-control activities in Korea. In order to do so, a system dynamics model is built and simulated in this paper. The following two sections provide literature and historical evidence for model conceptualization. A reference mode is presented as a result of base-run simulation and the sensitivity analysis conforms the validity of the model in section 4 followed by the section of conclusions and further research.

2. Literature

The question that modern industrial development might be creating environmental deterioration was posed in the study named Limit to Growth [8] for the first time. Since this study in 1971, environmental conservation has been posed in our socio-economic activities as directed in the study, and as a result there have been sequel studies in economics and other fields of social sciences. Although the studies apparently suggest various concepts and policy alternatives, there are few fundamental studies in the sense of operational meaningfulness [3]. That is, the studies evidently focused on searching the new development paradigms but they might neglect verifying the fundamental process of the impacts of industrial development on the environment.

Saeed [23], however, recently demonstrated with operational meaningfulness the relationship between industrial development and environmental responsibility. Industrial impacts on the environment are preliminarily assessed with the identification of modern institutional factors in developing countries which might impede any substantive step to addressing the sustainable development paradigms [17]. Among the factors he mentioned, the following factors are considered in this paper.

- Volume of industrial production that needs natural resources and discharges pollution
- Industrial structure for pollution generation and energy use

In addition, in order to formulate a model for the analysis on the environmental consideration of industries in the modern situation, it should be taken to specify further operational processes through which the costs are internalized. There are many pieces of evidences on those in both a corporate level and an industrial level of analysis [2, 5, 21, 25, 27, 28]. In the literature, one can find the term, eco-efficiency [26] of which the concept has been used to explain that there must be an economic incentive for a firm to willingly internalize the costs. Also several factors that make this fact possible can be pointed out as follows:

- increasing demand on environmentally friendly products and market innovation [5, 18, 28, 27, 29],
- open market and technological development [18, 26, 27, 29],
- saving cost and resource through waste reduction [21, 27, 28],
- strategic use of environmental legislation and international treaty [2, 28, 29].

These factors can be categorized as three main functions in a strategic management field [27]. The integrated green strategies in a corporate level consist of R&D strategy, manufacturing strategy, and marketing strategy in a functional level. Once the costs are willingly internalized in a firm which is eco-efficient, the firm willingly takes responsibility for its products throughout their life cycles and develops new and cleaner processes and products. Eventually its strategy moves away from the "end-of-pipe solution to the in-the-pipe solution".

A suggestion about the costs of clean-up [19] is especially interesting in the context of feedback loop. It presents that most of the regulation-based technologies for industrial waste will be driven out of the market by waste minimization approaches with obtaining technological attainability. That is, the development of clean technology will ultimately reduce the demand on the pollution-control sector. Chichilnisky [5], who suggested market innovation for the environment, argues:

> *"Markets are often considered enemies of the environment as of today, yet recent evidence points in the opposite direction, such that markets have evolved some of the most innovative and useful solution for global environmental problems".*

The impacts of industrial development on the environment are expected to be changed into more environmentally friendly one as the needs of market change in a dynamic situation.

The following factors are considered in this paper in order to describe the dynamic patterns of industrial impacts on the environment.

- Economic growth and industrial development
- Pollution generation by volume and structure of industrial production
- Regulation and amount of pollution controlled
- Costs of clean-up and incentives to investment on clean technology

These factors are, however, insufficient in fully explaining the reason of amplifying the costs of clean-up in a short term especially when pollution-control industry is considered as a supplier of the relevant pollution-control market [20]. The KIET study [10] gives some useful information on the growth pattern, industrial characteristics of the pollution-control industry. It suggests several problems in the industry as follows:

- increasing demand,
- lack of supply capacity.

The supply capacity is generally divided into quantitative and qualitative one. The quantitative one is related to the number of firms, the number of technical manpower, and production facility held by the industry. The qualitative one is the technology-embodied manpower and the end-of-pipe technology [6, 10]. Both might be short in the case of excess demand due to reinforced regulations. Consequently, short supply raises the level of the price in the market. It reveals in the evidence of technology import and its price growing up [4, 6]. The costs of clean-up, furthermore, which are rather reactive in this paper, are perfectly determined by the level of the price. It gives possibility that a feedback loop are presumed between the pollution-control sector and manufacturing firms which are interpreted as private sources of the demand in the market. That is, the following factors are also considered as important in this paper.

- Private and public demand [10, 13]
- Production of the pollution-control sector
- Quantitative supply capacity and price level in the pollution-control market

3. Historical Evidence

This section aims to delineate a system dynamics model of the pollution-control activities that have been discussed in the previous section. The several important variables that will be included in the model are examined with time series data in the following order.

- Economic growth and industrial development
- Pollution generation by volume and structure of industrial production
- Regulation and amount of pollution controlled
- Costs of clean-up and economic incentives to investment on clean technology
- Private and public demand, and production of the pollution-control sector
- Quantitative supply capacity and price level in the pollution-control market

3.1. Industrial Development and Pollution Abatement

- Economic growth and industrial development

The following historical evidence is related to industrial development, especially to the growth of the manufacturing sector. Economic growth pattern (the series of GDP) in Figure 1 may be considered as exponential one at the rate of about 10% since the year 1985. The average portion of the manufacturing sector in GDP is about 25%. GDP growth will be sustained up to 2000, but its rate will be gradually decreasing to 7% during the period [12].

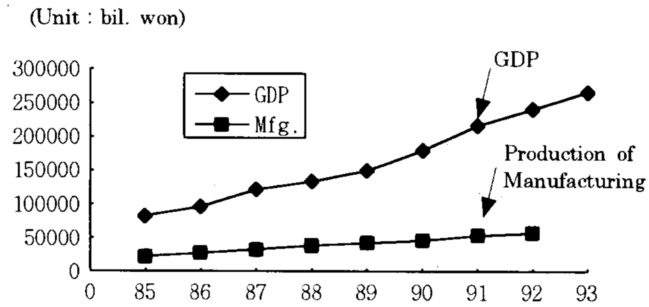

Figure 1. GDP and Production of Manufacturing SectorData Source: [12, 14]

• Pollution generation by volume and structure of industrial production

Pollution generation increases as the volume of manufacturing and national production increases. The growth rate of pollution generation is greater than that of manufacturing and national production [16]. The amounts of pollutants obviously amplify as the production of the manufacturing sector increases as depicted in Figure 2.

The manufacturing sector had been adjusted until the early 1990s toward industrialization and motivation of export since the 1970s. In the mean time, the structural adjustment led to high production volume in the heavy industries

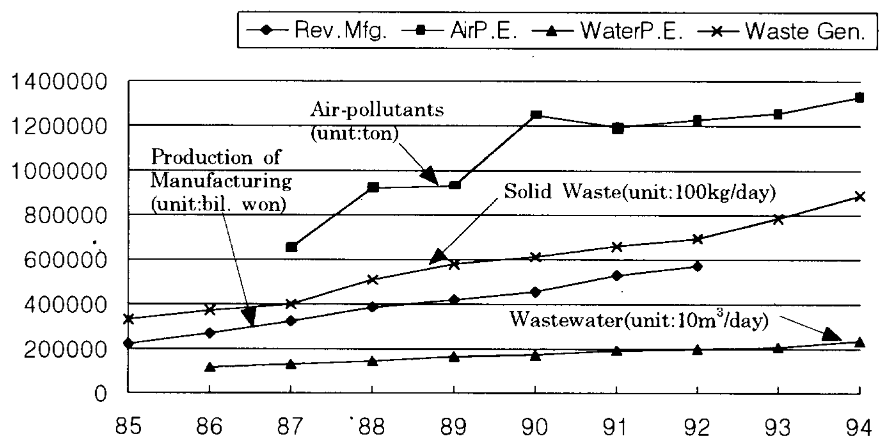

Figure 2. Production of Manufacturing Sector and Pollution Emission Data

such as chemical and steel industry to produce a large amount of air pollutants, effluents and wastes [1, 11]. The current portion of major polluting industries in GDP is about 15% and it is supposed to decrease down to 10-12% by the government policy [12].

- Regulation and amount of pollution controlled

Figure 3 shows that there is a gap between the amount of wastewater generation and the amount of wastewater emission. The gap is due to the pollution abated by the regulation.

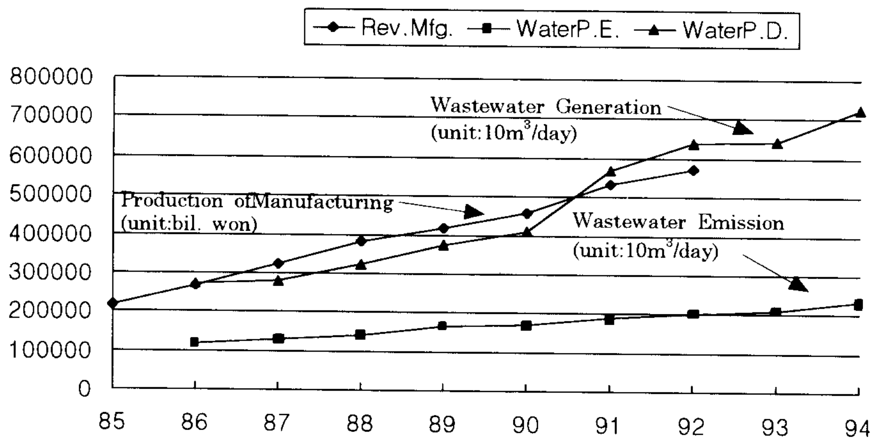

Figure 3. Wastewater Generation and Emission Data Source : [12, 15]

The difference between the wastewater generation and emission can be interpreted as the amount of wastewater abated. This statement can be applied to the case of air pollution and solid waste generation. Figure 3 also shows that the amount of wastewater controlled increases as much as that of wastewater generation in order to reduce the amount of wastewater emission.

- Costs of clean-up and economic incentives to investment on clean technology

It is pollution-control costs that are inevitable in the operation of pollution-control activities. The costs of clean-up are commonly generated in two ways. For most cases, one is the cost relevant to equipment setup and the other is associated with operation and maintenance. A questionnaire survey of manufacturing firms illustrates that the latter is about 40% of the former in Korea [15].

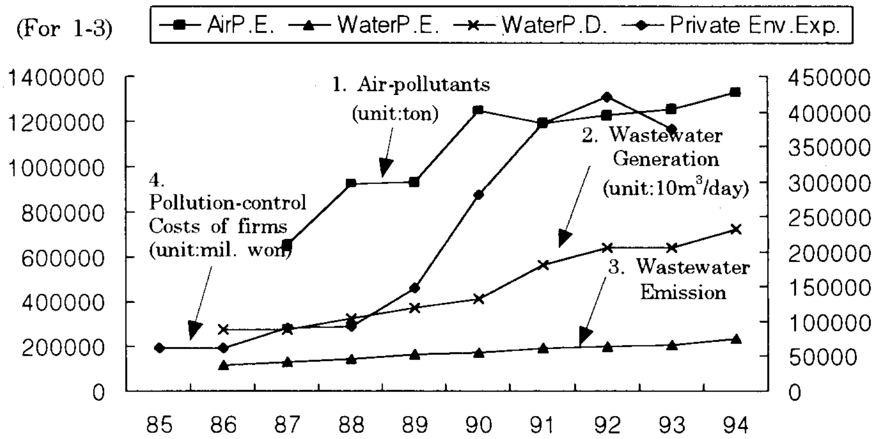

Figure 4. Pollution Control Expenditure of Manufacturing Sector Data Source : [12, 14, 15]

Figure 4 demonstrates that the pollution-control costs have grown in a surprising way. It reflects that there are growing economic incentives to investment on clean technology in order to avoid the burden of the clean-up costs.

3.2 Pollution-Control Sector

- Private and public demand, and production of the pollution-control sector

The pollution-control cost in private firms is described as private demand on the pollution-control industry in Figure 5. There are also two more indicated sources of demand such as public and export demand. The public and private demand has rapidly increased since the year 1989. The production volume of pollution-control industry seems to catch up well with the demand except when in 1993. Significant lack of supply capacity is regarded as a reason.

- Quantitative supply capacity and price level of pollution-control market

The shortage of supply capacity comes mainly from the lack of quantitative supply capacity in Korea, especially from the lack of qualified firms. In 1993 the government strengthened the qualification standards on firms' establishment in terms of finance, technology and manpower. As a result, a number of firms had their licenses revoked in that year [15]. The firms recognize technological problems, shortage of technical manpower, and financial instability as the most serious problems in their expansion of the production [10].

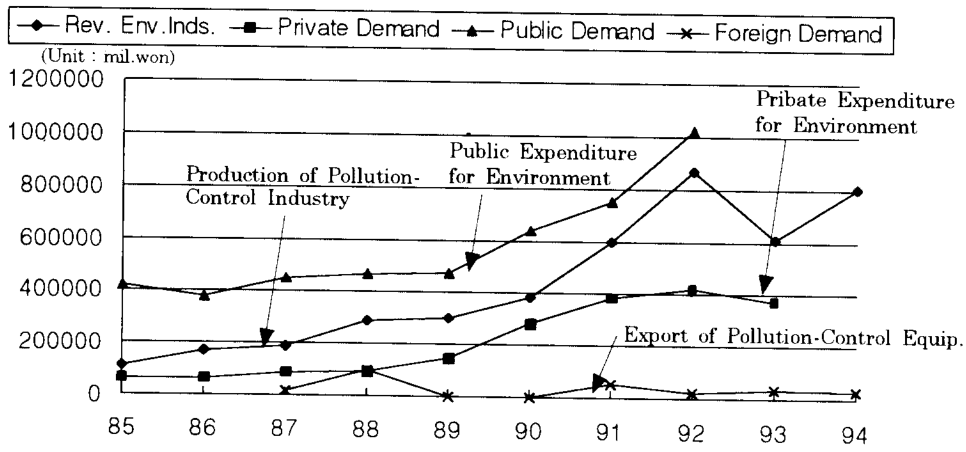

Figure 5. Demand on Pollution-Control Industry and Production of Pollution-Control Industry Data Source: [12, 14, 15]

4. The System Dynamics Model and Behavior

4.1 Dynamic Hypotheses and Causality Graph

Many pieces of empirical and historical evidence are investigated in the section of Literature and Historical Evidence respectively. Based on the evidence, dynamic hypotheses are presented below as the verbal descriptions of the causality that motivate system thinking [22].

- The production of the manufacturing sector is determined by economic growth and structural adjustment.
- The level of pollution generation in the manufacturing sector is affected by the production volume of the manufacturing sector and the diffusion level of clean technology.
- The amount of pollution controlled and its costs are determined by regulation and the level of pollution generation.
- The demand on the environment industry (pollution-control industry) comes from the pollution generation of the manufacturing sector and regulation.
- The demand on the environment industry encourages the investment on pollution-control technology.

- When the supply of the environment industry does not catch up with the demand, the price level of the market will go up.
- Growing price level pushes up the costs of clean-up and gives firms an incentive to redesign production processes, which results with a time delay in investment on clean technology.
- The investment on clean technology can help its diffusion faster so as to

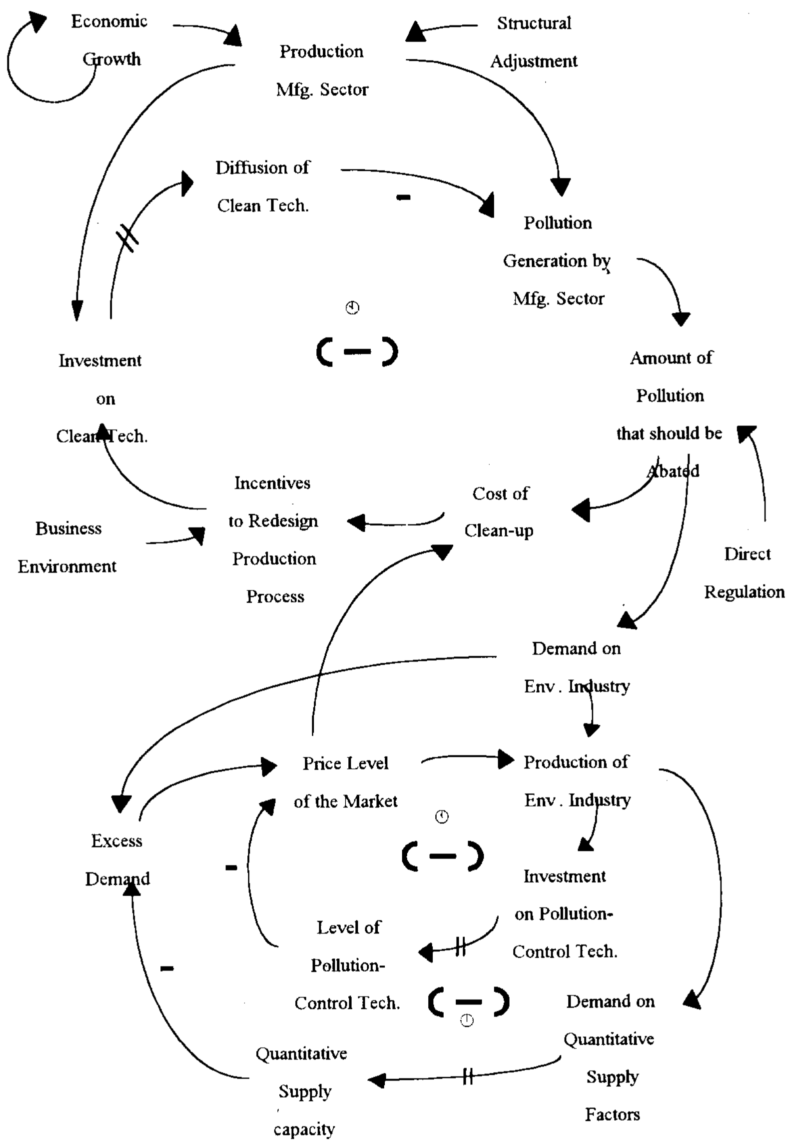

Figure 6. Causality Graph of Pollution-Control Activities

reduce the level of pollution generation.

- The reduced level of pollution generation negatively affects the demand of the environment industry.

A graph of causal relationship is depicted in Figure 6 according to the set of dynamic hypotheses. It simply contains the two main part, one of which is concerned with the pollution-control activities of the manufacturing sector in Korea while the other is concerned with the market situation of the pollution-control sector.

The causal relationship can be represented by feedback loops in system dynamics. Dynamic behavior patterns are generated by the interplay of feedback loops. Combinations of positive and negative feedback loops are capable of generating a wide variety of dynamic behavior patterns.

In the conventions of causal loop representation, we assign a *positive or negative* algebraic sign as a direction of causal effect to link. If a change in the cause makes the effect change in the opposite direction, place a negative sign symbol adjacent to the arrow associated with the link. If a change in the cause leads the effect to change in the same direction, do nothing. In Figure 6, for example, we do not mark the link between "Production Mfg. Sector" and "Pollution Generation by Mfg. Sector" because the *increasing* production of manufacturing sector leads to the increasing pollution generation. In case of the link between Diffusion of Clean Tech. and Pollution Generation by Mfg. Sector, we mark a negative sign because the increasing level of clean technology leads to the *decreasing* pollution generation by the manufacturing sector. The hatch mark(‖) on the arrow from "Investment on Clean Tech". to the "Diffusion of Clean Tech". indicates that this relationship acts with some delay.

Let us explain briefly how to assign polarity to the loop. Begin with any variable in the loop. Either increase or decrease it. Then, trace the resulting string of changes around the loop and back to the initial variable. If the returning signal causes the initial variable to change in the same direction, the loop is *positive*. If the returning signal causes the initial variable to change in a direction opposite to its initial change, the loop is *negative*. Conventionally we indicate the polarity of the loop by placing an appropriate algebraic sign in the parenthesis at the center of the loop. For example, the loop denoted by ① in Figure 6 represents a negative feedback loop. In order to see how the loop is negative, begin with "Pollution Generation by Mfg. Sector". *Increasing* "Pollution Generation by Mfg. Sector" means increasing "Amount of Pollution that should be Abated" which results in the increasing "Cost of Clean-up". The more the firms pay the "Cost of Clean-up", the more "Incentives to Redesign Production Process" they receive. This makes it possible to make more "Investment on

Clean Tech". which leads with a time delay to the higher level of the "Diffusion of Clean Tech". The higher level of the "Diffusion of Clean Tech". means the *decreasing* "Pollution Generation by Mfg. Sector". The linkage of two negative feedback loops such as ① and ② creates a new positive feedback loop.

4.2 Simulation and Reference Mode

The reference mode is generated by base-run simulation. The model derived in the previous subsection is simulated over the fifty years(1985-2035) and depicted in Figure 7 as a graph of several important variables: production of the manufacturing sector, cost of clean-up, level of clean technology, and production of the pollution-control sector.

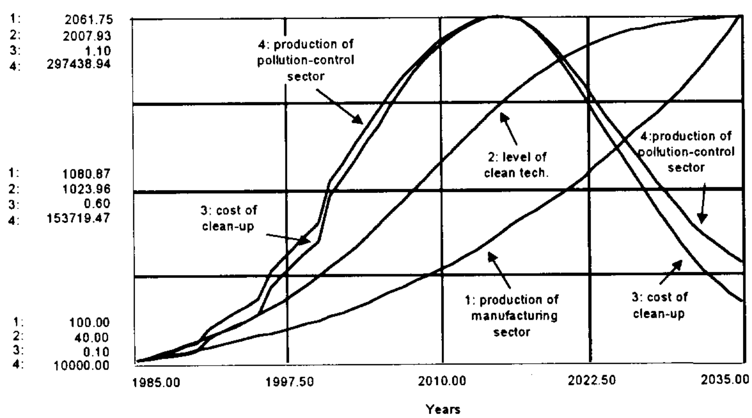

Figure 7. Reference mode

The growth pattern of the production of the manufacturing sector is of an exponential mode subsumed a minor variation by the structural adjustment and GDP growth. The growth of clean technology follows an S-shaped (logistic) growth mode [7]. The behaviors of the cost of clean-up and the production volume of the pollution-control sector show an overshoot and collapse structure.

Both the growth of the pollution-control sector and that of the cost of clean-up show a rapid growth pattern during the period of 1990-1991, 1995-1996, and 2000-2001. The reason of this pattern is due to the regulations strengthened in those time periods. The regulations affect the demand of pollution-control activities, thus accelerate not only the upward trend of the price level in the pollution-control sector but the burden of the costs of clean-up in manufacturing firms.

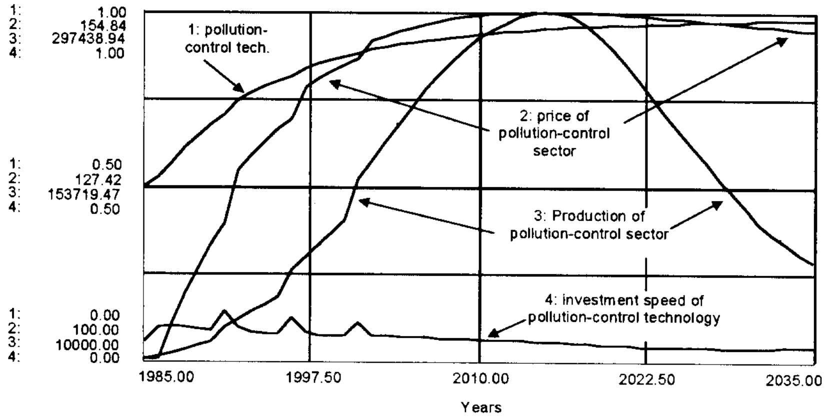

Figure 8. The Dynamic Behavior of Pollution-control Industry

The amount of pollution to be controlled means the demand for the reactive pollution-control sector. The demand and the price in the market determine the production of the pollution-control sector. The price gradually recedes after it reaches the peak in Figure 8. It reflects the prices downward rigidity in the market of the pollution-control sector.

The pattern of pollution-control technology in Figure 8 resembles exponential growth pattern modified by an upper bound. The level of the pollution-control technology 1.00 means that the technological level of Korea is equal to 100% of the level in the most developed countries. The difference between the level of Korea and that of the most developed countries is expected to be gradually decreasing. Moreover, the level of the pollution-control technology and its investment speed depend on the demand and the regulations.

Simulation results suggest that stringent regulations amplify the clean-up cost, the demand/price in the pollution-control sector and affect the level of the pollution-control technology. And the regulations lead to the development and diffusion of the clean technology in the manufacturing sector and ultimately lead to the overshoot and collapse structure of the pollution-control sector. From the dynamic behavior of this phenomenon, we can deduce the following problems to cope with in the future:

- instability of the clean-up cost due to the regulations and the price of the pollution-control sector (short-term behavior)
- unemployment and overinvestment due to the overshoot and collapse of the pollution-control sector (long-term behavior)

4.3 Sensitivity Analysis and Findings

The sensitivity analysis shows us how sensitive the dynamic behavior of an important variable is to variations of the parameters assumed and estimated in the model. The implicit assumption of system dynamics model is that: *It's the relationship, not the numbers, that deserve primary attention.* In other words, our main interest is to find out the sensitive parameters of which different values may produce different behavioral patterns from the original reference mode. Those parameters detected enable us to address a meaningful policy. The parameter specifications and the results of sensitivity simulations are presented in Table 1.

Most estimates of the parameters in base-run simulation come from the historical data. Let us present how the estimates of the parameters can be employed in the model. The estimate of the portion of manufacturing sector in GDP is 25% as explained in section 3.1. As for the estimate of pollution generation rate, the respective average generation rate of air pollutants, effluents, and solid wastes is about 16%, 21%, and 13% [12, 15]. Thus the overall average is 17%. This result looks similar to that of Lee's work [16].

The emission standard is used in this paper as the direct regulation by which the needed amount of pollution generated is controlled in such a way that the needed amount of pollution controlled can be calculated as the amount of pollution generated multiplied by one minus emission standard. The level of the regulation as of 1985 is assumed to be 60% based on an average of each portion of treatment statistics in pollutants, effluents, and wastes [12, 15]. It means that the 60% of pollution is emitted as being untreated in 1985. In addition, the emission standard is devised as the exogenous variable in the model to be reinforced every five years up to 2000 as explained in section 3.2.

The initial level of the pollution control technology is assumed to be 50% according to the survey result in [10]. The questionnaire survey shows that the respective level of technology for simple equipment, moderate equipment, and complex equipment is about 80%, 60%, and 10% of the level of the technology in developed countries and the overall average is about 50%.

The results of sensitivity simulations confirm that most parameters and exogenous variable are not critically altering the dynamic behavior patterns, even though these can amplify the absolute values of the variables. However, one of the interesting findings is the shift of the turnover point representing the overshoot and collapse structure of the pollution-control sector due to the clean technology. It is the clean technology not the end-of-pipe technology that can play a significant role in the pollution control in the long run. In the second row of the Table 1, the investment speeds of clean technology, devised as the measure of catalyzing the diffusion of clean technology, make the turnover point shift. Figure 9 shows the locus of the turnover points representing the diffusion level together with the associated turnover years.

Table 5. Results of Sensitivity Simulation

Objects	Specs	Results(%:Degree of Amplification)
The Portion of Mfg. Sector in GDP	5% only after 1995 compared to Base-run: (-5%)-(0)-(+5)	- Production(Mfg.): 77.3%-100%-122.7% - Production(PCS): 92.2%-100%-107.8% - Cost Clean-up: 85.5%-100%-114.8%
Investment Speed of Clean Tech.	0.2-0.25-0.3-0.35-0.4 (Base-run: 0.3)	- Turnover Points: Level of CT(year) not exist - 0.81(2023) - 0.74(2015) 0.65(2009) - 0.63(2006)
Pollution Generation Rate	0.13-0.15-0.17-0.19-0.21 (Base-run: 0.17)	- Production(PCS): 43.1%-64.4%-100%-158.9%-255.6% - Cost Clean-up: 33.7%-58.4%-100%-169.3%-283.3%
Emission Standard	Initial Level in 1985 (Base-run: 0.6) 0.48-0.54-0.6-0.66-0.72	- Production(PCS): 78.4%-89.3%-100%-110.3%-120.3% - Cost Clean-up: 78.3%-89.2%-100%-110.4%-120.5%
Initial Level of PC tech.	0.4-0.5-0.6 (Base-run: 0.5)	- PC tech in 2000: 0.85-0.87-0.89 - Price: 108.4%-100%-92.1% - Production(PCS): 108.2%-100%-92.2% - Cost Clean-up: 108.2%-100%-92.2%
Intercept: Investment Speed of PC tech.	0.03-0.05-0.07 (Base-run: 0.05)	- PC tech in 2000: 0.82-0.87-0.91 - Price: 107.6%-100%-94.3% - Production(PCS): 107.2%-100%-94.5%
Slope: Investment Speed of PC tech.	0.1-0.2-0.3-0.4-0.5 (Base-run: 0.2)	- PC tech in 2000: 0.83-0.87-0.9-0.93-0.95 -Price:106.6%-100%-94.9%-90.9%-87.8% - Production(PCS): 106.3%-100%-95.1%-91.3%-88.2%
Variation of PC price	0.4-0.5-0.6-0.7-0.8 (Base-run: 0.6)	- PCtech in 2000:0.87-0.87-0.87-0.87-0.88 - Price: 86.9%-93.3-100%-106.9-114.3% - Production(PCS) & Cost Clean-up: 87.2%-93.5%-100%-106.8%-114.0%
Slope of Other Demand	22-25-28-31-34 (Base-run: 25)	- Price: 99.6%-100%-100.4%-100.8%-101.3% - Production(PCS):

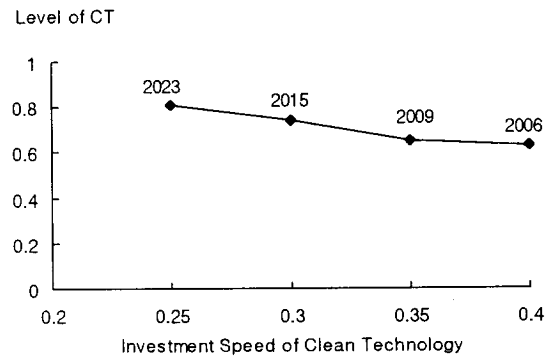

Figure 9. Locus of the Turnover Points in the Overshoot and Collapse Structure of Pollution Control Sector

The turnover point means the turning point in the diffusion level and the year in which clean technology can reduce the pollution generation substantially. This implies that the amount of pollution generation reaches its maximum at the turnover point. The higher diffusion level of clean technology at the turnover point means that there is a larger amount of pollution generation to be controlled. So it is quite natural that it takes a longer time to reach the turning point in time even with the higher diffusion level. Again, it is the clean technology not the end-of-pipe technology that can play a significant role in the pollution control in the long run. This implies that demand-pull strategies for the end-of-pipe technology is inappropriate for the challenge to meet the overshoot and collapse structure of the pollution-control sector. Therefore, the problems due to the overshoot and collapse structure may be efficiently avoided by such policies that can promote the diffusion of clean technology. Moreover, the development of technical manpower without a time delay is also considered as an important factor that promotes this technology-push strategies.

5. Conclusions and Further Research

A simple system dynamics model is applied for understanding the underlying patterns of feedback and dynamics in the pollution abatement activities in

Korea. A series of empirical evidence and causality model are presented and base-run simulation and sensitivity simulations are performed to seek a dynamic behavior of the model.

Simulation results suggest that promptly strengthened regulations amplify the clean-up cost, the demand/price in the pollution-control sector, affect the level of pollution-control technology and as a result, bring the burden of the cost of end-of-pipe control activities to the manufacturing sector in a short term, while the regulations lead to the development and diffusion of the clean technology in the manufacturing sector and ultimately lead to an overshoot and collapse structure of the pollution-control sector.

These dynamic modes cause not only the cost burden for the manufacturing sector in a short term but also the withdrawal of facility investments and human resources for the pollution-control sector in a long term. The first problem seems to be inevitable, but as for the second problem, the diffusion of clean technology is of much influence on the turnover point of the production in the pollution-control sector, and thus technology-push strategies for clean technology should be considered.

The future direction of this research would be to develop an elaborate model that provides solutions through the policy tests for the above problems addressed from the reference mode in the paper. There are, of course, limitations to our research although we try to describe the pollution abatement activities in terms of the dynamic causality and to verify the short- and long-term dynamic behavior of the activities. For example, the technology-push strategies are approved to be effective in the paper but it can not deal with the question to what degree the strategies would be efficient. This remains to be done in further research that should devise the detailed process of the clean technology development.

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