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Leverage Strategy to National R&D Investment in Korea:

A System Dynamics Approach

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Leverage Strategy to National R&D Investment in Korea:

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Abstract

Dilemmas surrounding investment decisions for national research and development projects include difficulties of determining the total funding amount (the strategic loop), R&D systems (the structural loop), and the process of realizing initial investment objectives and priorities by assigned researchers (the efficacy loop). This study purports to arrive at a feasible policy alternative to these decisional dilemmas by providing a simulation model that can detect inherent problems within the unobtrusive dynamic structure of the Korean national R&D investment institution.

The simulation model we introduce in this study maps out the cyclical causal nods of the Korean R&D investment institution that has produced sub-optimal investment decisions. We noticed that over the years the Korean R&D investment institution has made substantial commitments to the expansion of total funding packages awarded to selected national R&D projects. Increases in the dollar amounts of these targeted projects resulted in the stage-by-stage evolution of Korean technologies. It was possible for us to observe that the said technological evolution resembled paradigmatic changes similar to the ones we can identify in the evolution of a scientific body of knowledge. However, our simulation results show that enormous side effects and unnecessarily long inter-stage temporal gaps also surfaced as technological innovations progressed from one stage to another. This affirms our initial premise that the Korean national R&D investment institution, like its counterparts in other industrial countries, is

mired by decisional dilemmas of setting investment priorities and R&D amount. What demarcates the Korean national R&D investment institution from its international competitors is the unusually high discrepancy between the total investment stock and consequential research results that have the benefit of international recognition.

Previous studies have failed to address these structural issues inherent in the Korean national R&D institution, especially on the dynamic structure of making funding decisions. Although some extant studies noticed the ongoing decisional problems within the Korean national R&D institution, empirical simulation models that could detect underlying structural anomalies rampant in the institution have not yet been fully developed or tested. In this study, however, we identify three cyclical loops of strategy, structure, and efficacy that are continuously interacting with each other to produce both intended and unintended outcomes of national R&D projects. We then built up simulation models of each loop to unravel its complex web of causal nods by using a computer software program STELLA 5.1.1.

Three simulation models produced various results for different scenarios. In sum, we found that emphases on application and “add-on” or developmental technologies resulted in long inter-stage temporal gaps, although their short-term economic benefits were obvious. In a similar vein, myopic investments in specifically targeted technologies in strategically designed R&D projects led to decreasing levels of absorptive capabilities, whereas far-sighted investments brought in adversary results. Finally, we found that an initial investment package did not have significant impact on the level of researcher efficacy, which augurs a more complex dynamics of researcher motivation structures than is usually assumed. Therefore, in the Korean case, it is imperative that the national R&D institution concentrates resources in long-term and far-sighted projects to enhance strategic technologies, while it is necessary for it to increase funding for fundamental research projects to beef up its R&D capabilities.

Introduction

This study is an empirical investigation of how decisions regarding national R&D investments are made in Korea. We are interested in locating structural problems occurring with the Korean NIS in the face of globalization and mad technologies through system dynamic approach. In so doing, we intend to devise ways of ameliorating problems within the NIS investment decision-making process by providing policy implications. The Korean case is an interesting testing ground for a system of dynamic modeling because of its drastic changes in the NIS sector due to rapid economic development and ferocious reaction to mad technologies.

Pavitt (1988) argued that international gaps in researcher qualifications and R&D expenditures could provide countries with catalysts for catching up with a global technology leader or even outstripping such a leading nation. Innovation is an important element of beefing up national competitiveness and productivity, and R&D serve as basic investment resources for innovation (Bozeman and Melkers, 1993). In the past decades, technological innovations have progressed drastically, making it impossible to think of national competitiveness without their contribution (Edler et al., 2002). In a similar vein, scholars emphasized the importance of national innovative capacities that can improve the national technological level and knowledge stocks through a virtuous cycle (Lee et al., 2001). In general, economists have treated technological innovation as a key production factor, responsible for productivity increases, while agreeing with the idea that R&D is a fundamental basis of technological innovations (Borrus and Stowsky, 1999).

Throughout the last decade, expenditure increases in R&D among OECD countries were accompanied by changing trends in how R&D funds were allocated and eventually implemented. It was discerned that R&D needs and opportunities often determined project orientations, while expenditures were implemented in linkage with end-users and their R&D budgets (Webster, 1991). American NIS spending, the largest in the world, is also at a juncture, awaiting a final decision by the government regarding future changes to allocation and implementation of R&D funds (Bonvillian, 2002; Korn et al., 2002).

It is obvious that private sector corporations have played central roles in bringing about technological innovations in other countries in the past (Pavitt, 1998). However, in Korea, it was the government that has played a similar role, and it is expected to continue to assume this role in the future. In 2002, R&D expenditure in Korea finally reached $11.4 billion, 2.91% of total GDP, after three decades of efforts by the government and private corporations (MST, 2003). These figures are not at all different from OECD averages (2.5-3%). In addition, OECD countries selected Korea as a model nation for reforming its NIS funding structures to reduce funding overlaps and concentrate resources in a few targeted areas. These areas constitute national strategy fields under the banner of "selection and concentration" (OECD, 1999).

However, the Korean NIS suffers from an inefficient structure of high R&D investments with a low level of innovation breakthroughs. Why did this structure of "high cost-low efficiency" come into being in the Korean NIS? Is this a short-term effect caused by a rapid expansion of R&D investments that exceeded the speed of a corresponding increase in R&D capabilities? Or is it a long-term, structural malady due to the quick transition to innovation-first strategies, which might have triggered time-lag effects between new innovation directions and traditional R&D paths?

We want to analyze the system-dynamic structure of the relationships between factors that intervene in the process of making NIS investment decisions in order to map out an unobtrusive structure of dynamism that can be found in every step of the Korean NIS decision-making procedures. We believe that this analysis will locate some of the policy leverages that can be applied to future decision-making procedures to increase NIS funding efficiencies. We present first issues on the Korean R&D investment system and its investment dilemmas, followed by the presentation of a simulation model that helps locate policy leverages based on system dynamic analyses. The analysis and interpretation of the simulation results will identify what is causing the structural inefficiency of the Korean NIS in the face of globalization and mad technologies, and finally we will provide policy implications.

R&D Uncertainties and Investment Dilemma

The Dilemma of R&D Funding Size

R&D funding size is important for two reasons. If R&D expenditure is too large, short-term financial stability is endangered. If the expenditure is too small, long-term competitiveness is threatened (Heidenberger et al., 2003). Although it is easy to assume that one's economic size determines R&D expenditures, it is not always certain whether the total funding size, in alliance with corporate end-users and collaborators, will bring about intended short-term financial stability and long-term competitiveness. NISTEP (1999) argues that empirical studies must follow previously ascertained theoretical contours regarding the size of R&D expenditures (e.g., Arrow's socially sub-optimal vs. Dasgupta and Stiglitz's redundant investments).

Stewart (1995) points out that NIS policymakers focused on choosing preferred sciences and technologies for the NIS projects, prioritized according to national objects, whereas the existing literature on the subject emphasized both structural and thematic priorities of NIS projects. Although NIS projects are appropriately determined as to their exact funding sizes, a dilemma may occur in determining investment priorities, depending on where policymakers want to place emphasis—on thematic, structural, or preferred area priorities. Heidenberger et al. (2003) finds that budget allocation rules devised to help determine investment timing and funding size did not produce positive results, as various unforeseen problems occurred during budget implementation. Keiting et al. (1999) also noticed what he calls "improvement paradox," refering to the failure of efforts to improve quality control and reengineering procedures.

According to *Science and Technology Plans*, published by the Ministry of Science and Technology, the Korean NIS funds two overall types of projects—strategic technological development (STM) and R&D capacity development (RCD). Both types of projects have one year long (short-term) and three year long (long-term) projects. STM projects are related to the so-called 6T industries (IT, BT, NT, etc.), whereas RCD deals with long-term projects that are designed to support the transition of the Korean economy to a 6T intensive one. If a funding balance is broken between these two separate project groups, we can foresee that an R&D investment dilemma will occur, similar to the so-called *kaizen* paradox, which results in a continuous reduction in R&D efficiency.

> *Research Question 1*: It is important to prioritize NIS projects without causing R&D investment dilemma, because they will enhance the flow of R&D resources and knowledge depository. However, is it possible to find a balance point for a correct combination of STM and RCD projects?

Dilemmas Caused by Myopic Investment Decisions

Uncertainties about the benefit of the current R&D investments to the future national interests invite various conflicts in the process of prioritizing NIS investments (Bloom, 1988). Consequently, a gradual increase in R&D expenditures occurs, as decision-makers opt for a larger funding package than that of the optimal level (Lundstrum, 2002). American firms are found to take a myopic posture of investing more in the projects that yield quick profits, than in the ones that require optimal-level investments.

As Lundstrum (2002) demonstrated, myopic investment strategies lead to mediocre R&D results, since they prefer projects of quick turnovers and, thus, distort the entire NIS investment policies. This American tendency is a typical example of decisional dilemma caused by myopia. Members of the National Science Council, who determine the final prioritization of NIS projects, face strenuous situations because of R&D uncertainties. A sudden expansion of the national R&D budget, time limits, and the myopic decision-making strategy may result in negative side effects by lowering the funding size for the NIS projects related to thematic priority groups (e.g., new researcher support, provincial science and technology development, etc.).

> *Research Question 2*: Expansion of the R&D budget, amid unclear investment guidelines, may continue to fund inefficient NIS projects that should have been terminated. Path-dependent investments, profit-oriented investments, and other myopic funding decisions based on the principle of selection and concentration can worsen the final R&D results. Is there any way to detect these problems beforehand and ameliorate the consequences?

Agency Problem and Decisional Dilemma

In R&D administration and inducing R&D results, conflicts between the initial intention of the government policy and the goal of representing researchers can ensue. The so-called 'agency problem' takes place because of information asymmetry between principals (the government) and agents (representing researchers). A typical scenario of moral hazards is when the principal wants to provide sub-optimal funding and the agent delivers R&D results whose quality cannot be easily measured. Information asymmetry leads to two-tiered moral hazards, as the government cannot check on the sincerity of R&D institutions, and the latter cannot evaluate efforts shown by their researchers.

In addition, if the government concentrates R&D resources in high-risk projects, including the development of new and cutting-edge technologies, to fight globalization and mad technologies, the expanded R&D budget *qua* slack capital can serve as a buffer to the changing global economic environment. However, prolonged investments in such high risk projects as nano-, bio-, and information technology development, which have a very low probability of success but may yield a big return if successful, will destroy existing technology stocks, as researchers will abandon traditional projects and take up new high risk items. Therefore, it is doubtful whether the slack capital, invested in cutting-edge technologies, as a buffer to globalization and mad technologies, can perform its intended function, especially when the Korean NIS still suffers from the "high-cost/low-productivity" syndrome.

> *Research Question 3*: Is it possible to find a solution to principal-agent problems that result from the disaccord between the strategic loop that prioritizes NIS projects

and the effective loop that induces researcher commitment? Also, is it possible to find a solution to the problem of the inept slack capital?

Prioritizing NIS Projects in Korea

Braun (1998) described cognitive development within a scientific body of knowledge as a complex process of interaction between four subsystems of funding agencies: cognitive traditions and scenarios, motivations of researchers, and technological development. It was noted that funding agencies first receive cues from external interests in new technologies. The Korean NIS structure has two separate mechanisms of determining the priority of funding, which is under the purview of the National Science and Technology Council (NSTC), and getting approval of and distributing funding packages to researchers, a jurisdiction of the Planning and Budgetary Board (PBB). Recently, the PBB's role has been reduced to obtaining budgetary approvals from the National Assembly, while NSTC prioritizes and funds NIS projects. The overall coordination mechanism within the NSTC and the PBB involves a complex and dynamic structure of prioritizing NIS projects according to their structural, thematic, and scientific importance and determining funding sizes in consultation with the PBB.

The actual procedure for prioritizing and determining funding sizes is as follows. First, data is collected from the examination and evaluation of the projects granted in the previous year. Second, a new set of criteria and categories of new projects to be granted is pre-negotiated with the PBB, which provides information on the new R&D resource restrictions. Finally, these findings are reported to the president who resides over the NSTC meeting. In the NSTC meeting with the president, final decisions are made regarding the priority of each project to be funded. When the decisions are reported to the PBB, it will start the final budget allocation procedure. As can be gleaned from this complex decision-making process, national science and technology projects involve many layers of different decision makers, making the entire process complicated and political (Stewart, 1995). Since this political decision making process involves several layers of different decision makers, the Korean NIS decision making system is an area of institutional complementarity (Leoncini, 1998).

Causal Loop Diagram of Stratified Decision Making

Hansen et al. (1999) reported that the decision making process for distributing resources involves a three-tiered structure. The first tier deals with decisions made by such public agencies as DoD to protect their current capacity and expand their future power. The second tier is about distributing resources for different stages of R&D projects, and the final stratum is the decisions specifically made for distributing resources to a project that goes through different stages. The Korean system of decision-making involves a complex web of causal mechanisms that determine project prioritization, distribute funds to prioritized projects, and oversee R&D progress.

The causal nods of stratified decision making can be shown in a diagram as in Figure 1, which bears three different loops. The strategic loop determines the priority and funding size of R&D projects through coordination and discussion among PBB agents, professional R&D institutes, and researchers. Although decisions are based on the actual performance of previous projects and future feasibility of extant projects, bureaucratic inertia, evaluations based on short-term performances, and the trap of targeting and concentration will loom large in this loop. The second one is a structural or efficiency loop that affects the process of making decisions in the strategic loop by providing information on the circulation of R&D resources and how R&D projects were carried out in previous years. Analyses of the cyclical flow of R&D money and projects can give information on the complex web of individual and group interests in addition to the progress of R&D projects. The third one is an efficacy loop or researcher loop that is related to the correlation between researcher attitudes and R&D investment priorities. For example, the efficacy loop shows how the attitude of a software developer can make the entire R&D project smooth, although the project is actually about developing a new hardware system. Overall, these three loops can measure how external interests, including scientific and technological issues, individual project performance, and researchers' R&D activities, are continuously siphoned into the R&D investment system.

Figure 1. Three Loops in the R&D Investment System

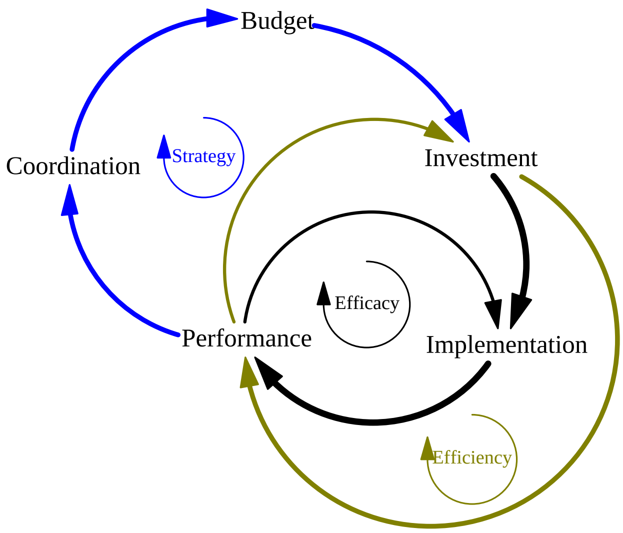


Figure 1 above indicates that the direction and consistency of the flow are related to the decision makers who prioritized R&D investments in the Korean coordination procedure. This means that the prioritizing system affected lower systems of decision-making, as all three loops are connected to each other, while end results also affected the prioritizing procedure as feedback.

Designing System Dynamics Models

As we clarified in the beginning, we intend to resolve decisional dilemmas noticed in all three loops that we described above. To do this our system dynamics model must be able to provide some leveraged indicators to show whether the Korean NIS has to expand or reduce R&D spending. If expansion/reduction is a possible policy alternative that the model suggests, which projects must be further funded and which must be stopped is another issue. Therefore, the choice of system dynamic modeling has to be justified for our purpose.

It has been noticed that strong correlation coefficients between R&D investment and R&D performance in a multiple regression model do not necessarily indicate that a causal relationship exists between the two variables. Occasionally, reverse causality between variables x and y is also discovered, when correlations are statistically significant (Oh et al., 2002). Also, although a procedural diagram can express mutual dependence of two particular variables, it simply reflects a still picture of otherwise very dynamic relationships (Senge, 1994). In R&D investment decisions, many different participants make decisions either simultaneously or at different times, while their actions and decisions mutually affect the other participants, and different steps and stages of decision making procedures are all closely associated with each other.

In order to understand a complex system, we need to master basic concepts of system dynamics, such as feedbacks, stocks and flows, time delays, and asymmetry (Sterman, 2002). Participants have different mental models when they try to make decisions regarding R&D investments. Subsystems also contribute to the complexity of the overall decision-making system. Changes in one variable will bring about similar changes in other variables of the same feedback loops. Therefore, a system dynamic model can be justified in the analysis of the Korean R&D investment system.

The first task in the construction of system dynamic models is to find core factors that affect the working of the Korean R&D investment system. In this chapter, we drew a feedback loop that consists of strategic, efficacy, and efficiency loops, based on our theoretical research and participant observation. We mixed both stocks and flows models in the construction of each loop in order to make it easy for us to generalize our findings in a conclusive feedback loop. Particularly, we divided NIS projects into basic, application, and add-on technology types and observed how they changed over time in order to find out policy leverages that are significant for the relationship between each loop. We used STELLA 5.1.1 in the design of each loop.

Strategic Loop

This loop coordinates the initial process of decision-making regarding R&D investments. Broadly speaking, coordinators are the government (PBB), professional institutes (KISTEP), and researchers. The government was assumed to be the party that makes decisions about the priority and size of R&D funding, whereas professional institutes and researchers were considered to react to, or interact with, the governmental decisions, based on R&D performance and future potential for succeess in new technology development. It is additionally assumed that project priority and funding size are determined by the distribution of power each party has in the coordination process (Lounamaa and March, 1987).

Activity levels intensify when participants have confidence in the future success of the R&D projects. Confidence is usually based on empirical inference, which is obtained by learning after either intended or unintended consequences occur. This process of learning takes the form of gradient search, because these consequences are a critical starting point of cognitive development. Periodic cognitive developments determine the level of activities taken up by participants in R&D projects.

Learning activities are reinforced by the evaluation of R&D performances. We assume that performance evaluators use only partial rationality or intended rationality to highlight only certain aspects of the project they want to emphasize. For example, researchers want to utilize research results for next round's funding negotiation, whereas the PBB highlights only research productivity for the money invested. On the other hand, professional research institutes want to take technological capacities into consideration, in addition to financial conditions.

Conflictual interactions between three actors, regarding project prioritizing and funding size, receive final coordination from the government. For instance, the Korean government publishes a guideline of R&D investments to make its policy intentions public (e.g., investment ratios for basic research to total investments), which eventually adds weight to a particular actor's interests and policy preferences. In other words, we devised a governmental decision making model that is subject to input from external actors. We express this model of distributing funds to each stage of a selected R&D project as follows:

$$T_{kt} = \frac{\sum_{i=1}^{3} f_{kt} A_{ikt}}{\sum_{k=1}^{3} \sum_{i=1}^{3} f_{kt} A_{ikt}},$$

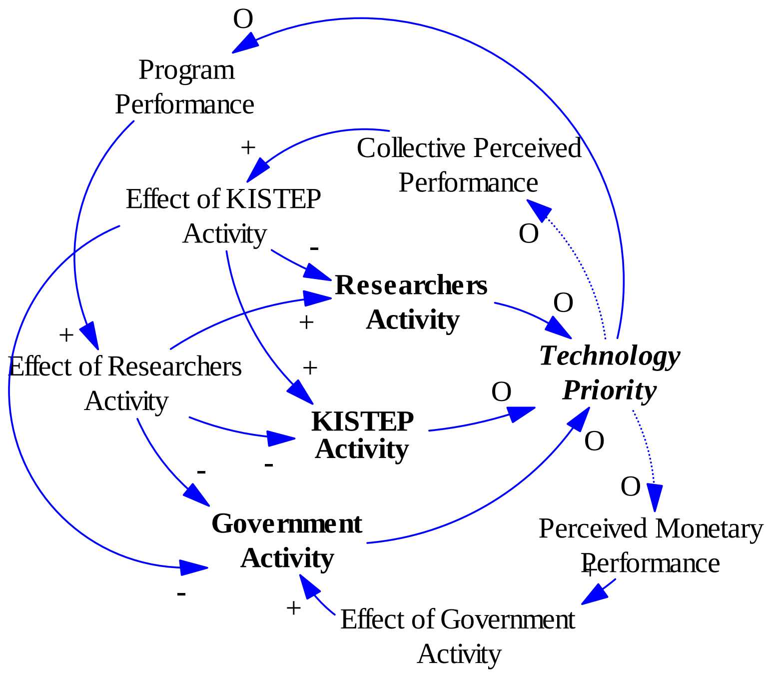
where f_{kt} is added weight on the decision coordination over a new technology of *k* during the period of *t*. Although technology had a 1x3 (basic, applied, and add-on) matrix initially, it later becomes a 3 (PBB, professional institutes, researchers) x 3 matrix, expressed by X. f_{kt} is a weighted value of an X_i factor of the matrix X during the period of *t*.

In addition, we assigned a 1 when each actor perceives opponents' changes in strategic postures. 0 was given when such perception was absent. It is obvious that increased interactions between actors enhance the chances of obtaining perception on such changes. We, thus, assigned the following scores for each actor for a heuristic purpose.

Actors	PBB	Professional Institutes	Researchers
Score	0.7	0.2	0.1

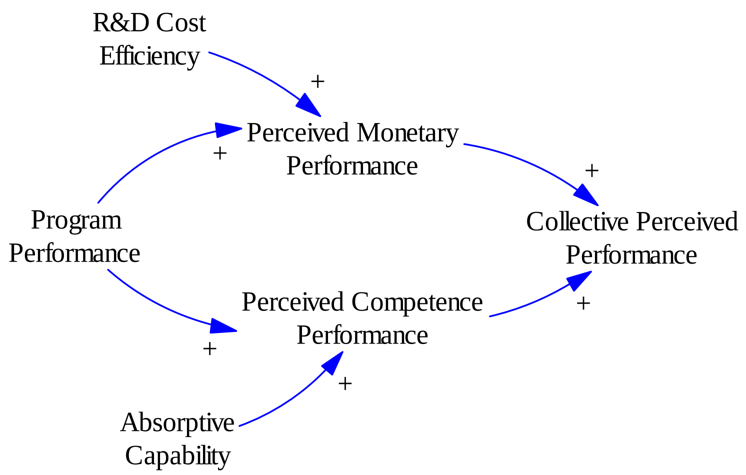
Finally, we added logical operators to decision coordination (T_{kt}) in order to reflect the importance of heuristic decision making at the time of the increasing number of current projects in progress with which the government and other participants have to deal. Decision makers often utilize heuristic methods of distributing R&D resources equally to extant projects when complexity increases, due to either too many cases or too many variables. The causal loop diagram (CLD) of the strategic loop, which determines the priority and funding size of NIS projects, is shown in Figure 2.

Figure 2. Strategic Loop



The strategic loop has a central structure that coordinates different R&D intentions held by three groups of participants and players, who set their levels of activities based on limited rationality and evaluations of previous studies. Individual or group perceptions will determine the outcome of project evaluations. We can produce a model of perceptions using the following stocks and flows models.

Figure 3. Model for Perceptions on Project Evaluation



As the figure indicates, performance evaluation of a project, where actual researchers are participating, starts from program performance, which is then diverted into monetary efficiency and knowledge accumulation dimensions. Depending on which dimension participants emphasize, performance evaluation changes. The monetary efficiency dimension refers to financial aspects of a project that are related to the ratio between project results and total investments. The knowledge accumulation dimension, however, emphasizes capacity aspects of a research project that are related to the ratio between knowledge being created and its relationship to previously created knowledge.

Efficacy Loop

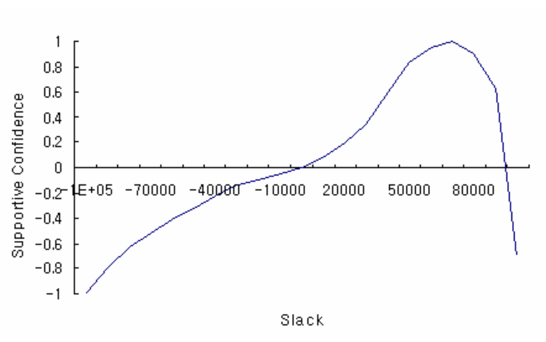
We designed the efficacy loop using two dimensions—attitudes toward R&D investments and those toward R&D performance. The first set of attitudes refers to how researchers react to slack resources allocated to their R&D research. Two consequences can occur when slack resources are allocated. First, researchers can be motivated highly, to the extent that innovative research is possible (Cyert and March, 1963). Research organizations with a large pool of slack resources can outperform others in terms of the number of subprojects they can run, which also provides research with psychological motivation to work harder than they would otherwise. When slack resource pools are absent, researchers rely on a routinized decision making pattern, resulting in the adoption of an exploitative, instead of explorative, research strategy (March, 1991). Perrow (1984) also argued that big accidents in a complex organization are "normal," since the lack of slack resources blocks any attempt at innovating organizations. In this sense, slack resources are fertilizers for technological and organizational innovation.

Second, slack resources can also motivate researchers to take risk aversive postures. Slack resources can unnecessarily prolong project periods, as researchers can try different alternatives to the solution of project problems. Slack resources, making it much easier for researchers to lengthen the project time frame, compensate for failures of these trials. Therefore, slack resources can have adverse effects on the organization's ability to adapt to changing environments (Thompson, 1967). In addition, in an agent-principal relation, agents can always privatize slack resources for personal use, instead of dispersing it organization-wide for group or organizational benefit, a typical example of moral hazard problems (Holmstrom, 1979; Jensen and Meckling, 1976).

In this context, we can easily detect that slack resources can be a cause of both motivational boosts and the pursuit of private self interests. An increase in slack resources certainly brings about positive reactions among researchers who are highly motivated to take up difficult tasks (Greve, 2003). However, excess amount of slack resources can easily create conditions for moral hazards. On the other hand, no slack resources (i.e., funding was provided at a sub-optimal level than was initially requested) will make researchers avoid difficulties and dangers, seeking sub-optimal research strategies and even sabotages to cause delays in generating research results.

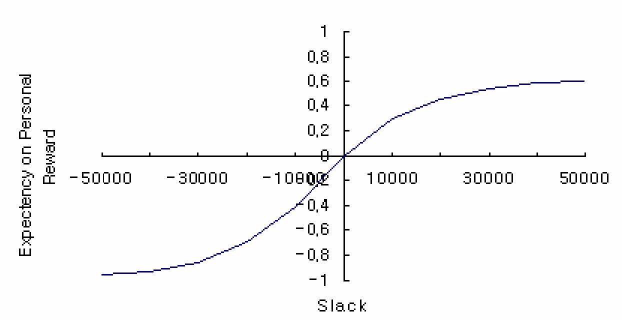
In our model of R&D efficacy we distinguished capacity-based slack from monetary slack. Capacity slack refers to the amount of R&D funding that exceeds researchers' R&D capacity. Capacity slack can motivate researchers to work harder than they would otherwise, although it can be a source of moral hazard problems, too. We assumed the relationship between capacity slack and researcher confidence in investment support to be asymmetrical as in Figure 4.

Figure 4. Relationship between Capacity Slack and Researcher Confidence



Monetary slack occurs when participating parties have different R&D expectation levels and oversupply research funding to researchers. Monetary slack is linked to personal reward expectation, as the oversupplied portion of R&D money is supposed to be converted into personal gain. Individual utility function shows that people take risk aversive strategies when behavioral consequences produce positive gains at the time of decision-making amid uncertainty; conversely they change to risk taking postures when behavioral consequences are in the negative (Kahneman and Tversky, 1979). In other words, the occurrence of slack resources leads researchers to the expectation of personal gain or reward, which then motivates researchers to be risk aversive. On the other hand, when no monetary slack occurred, researchers can take risks, because they might have to spend their own private monetary resources for the R&D project (Sitkin & Pablo, 1992; Wiseman & Gomez-Mejia, 1998). This relationship between personal reward expectation and monetary slack can be expressed in the following graph.

Figure 5. Monetary Slack and Personal Reward Expectation



In sum, slack resources affect researchers' risk preference pattern, which in turn influences researchers' attitudes toward their R&D projects. Since the utility function for risk-aversive postures takes a logistic growth function, while risk-taking postures generate an exponential growth function, we devised the following functions:

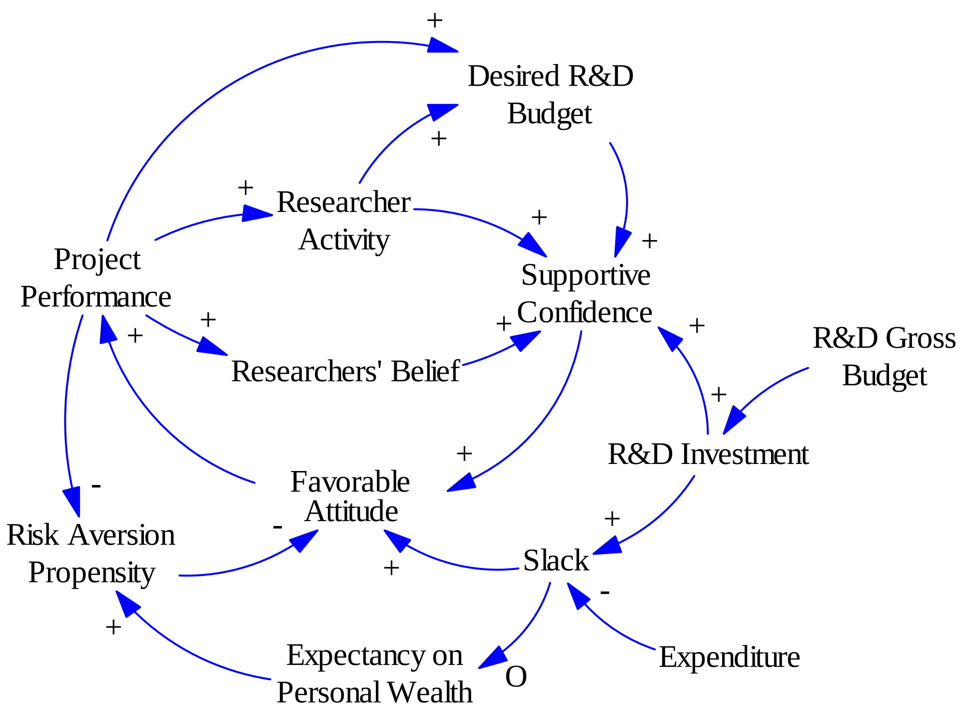
$$U(P) = 1 - exp(-rP),\ r \geq 0$$
$$U(P) = exp(-rP),\ r < 0$$
,

where r is a coefficient parameter for risk-aversion. The parameter is positive when researchers are risk aversive and negative when they prefer risks. x refers to monetary performance or project performance. It is thus argued that researchers' attitudes are determined by their confidence in their own research abilities and risk aversive postures toward the resource slack. Its function is:

$$FA(t+1) = FA(t) + U(P)C(Slack)$$

Our next concern, research performance, can be examined by both quantitative and qualitative means. The quantitative option is simply to count all completed projects within a given deadline, while qualitative measurement is presumed to be related to researchers' attitudes, because it is more difficult to utilize than the quantitative measure. Therefore, the number of completed projects measures research performance by researchers' actual attitudes. Actual attitudes are a concept that incorporates both will and real activity levels held by researchers and are expressed in terms of the level of confidence about research performance held by researchers multiplied by their actual research activities. We have already assumed that the level of confidence is correlated with researchers' positive attitudes toward their projects. The efficacy loop has the following stocks and flow structure:

Figure 6. Modeling of Efficacy Loop



Efficiency Loop

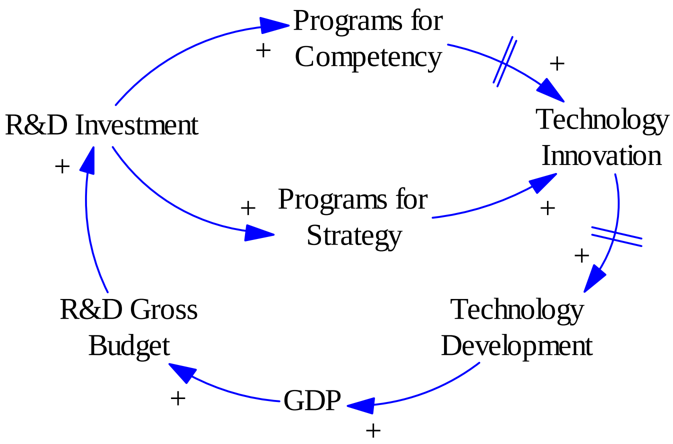
We preceded the modeling of the efficiency loop from two dissimilar aspects. One is a flow of a program (or project), and the other is a flow of the implementation of R&D budgets and budget decisions for the next fiscal year. As we indicated earlier, NIS projects can be classified into competency building programs and strategic technology development programs. The process and behavior of each type of project are different from case to case.

Capacity building programs include foundational science, human resource development, and short-term projects. Therefore, we assumed that knowledge accumulation will grow exponentially past a tipping point, although it would not be visible in early stages. On the other hand, strategic technology development programs usually include long term projects for developing strategically targeted new technologies, although they quickly adapt to changing environments. Therefore, we assumed that the finished results of each project might be very visible, although new technologies can easily become obsolete when the market is saturated. In the long run, strategically developed technologies disappear from the market.

On the other hand, strategically developed technologies maintain linkages between different dimensions of technologies. In a linear relationship between stages of technological development, basic technology serves as a basis for application and add-on technologies. This linear relationship is determined by absorptive capacity, where learning capacity of digesting foreign technologies and applying them to domestic conditions is a key to success (Cohen and Levinthal, 1989, 1990).

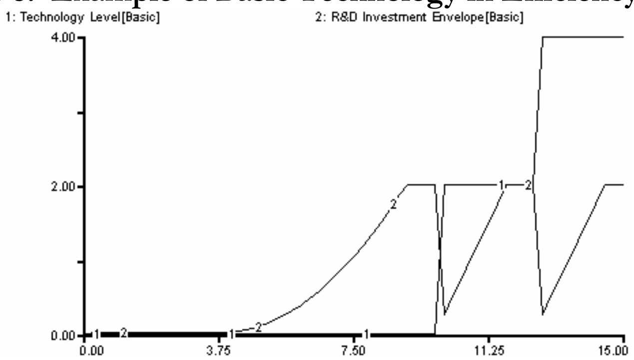
Based on the above viewpoints, we propose the following stocks and flow structure. We presumed that researchers are rotated every term for capacity building programs, whereas they are rotated every three terms for strategic technology development programs.

Figure 7. Modeling of Efficiency Loop



The accumulation of new knowledge will serve as a foundation for new projects in the future, which means that technological development corresponds to the number of projects. Innovation occurs after certain periods of time, as paradigms change. A virtuous cycle of technological development, paradigmatic changes, and innovations continues. The following shows the example of this cycle on basic technology.

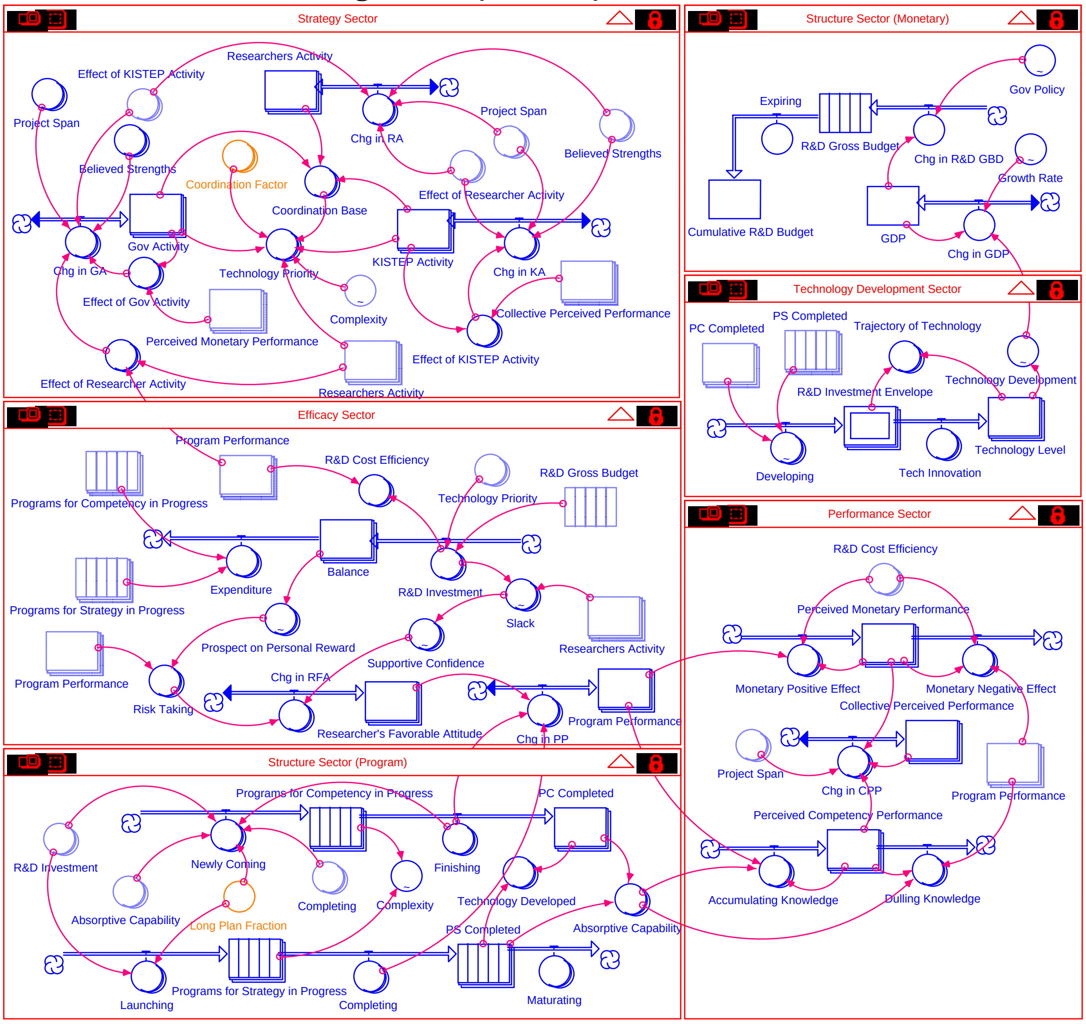
Figure 8. Example of Basic Technology in Efficiency Loop



Monetary flows deal with the issue of how research performance affects the distribution of funding to future R&D projects. Research performance of a project is measured by it financial performance, using the ratio between productivity and its total expenditures. Financial performance is then a source of decision for future terms. When technological development contributes positively to economic development, an increased economic size can also lead to larger R&D budgets. Decision making based on financial performance usually occurs in the investment of strategic technology development.

As so far, we present the causal loops related with the national R&D investment. Through those causal loop diagrams, we can have whole system dynamics model:

Figure 9. System Dynamics Model



Findings and Policy Implications

We will introduce findings and discuss their implications, using three types of technologies (foundational, application, add-on), three types of programs (capacity building, strategic technology development), and researcher attitudes. Findings will be followed by a short discussion on policy implications.

First, we asked a normative question of how to devise desirable decisions at each R&D stage in the strategic loop. Manipulating coordination factors during each R&D stage, which yields different investment effects and technological innovations, can do this. When factors are set to favor foundational technologies (i.e., foundational, application, and add-on technologies are sent at 0.8, 0.1, 0.1), the following results.

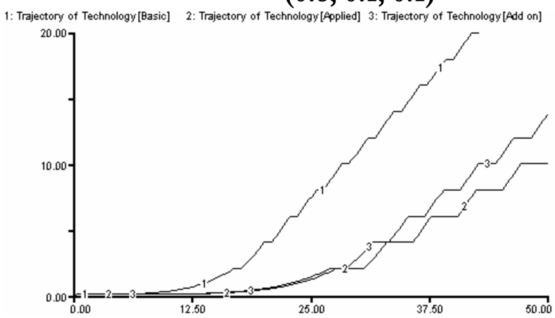


Figure 10-a. Technological Development (0.8, 0.1, 0.1)

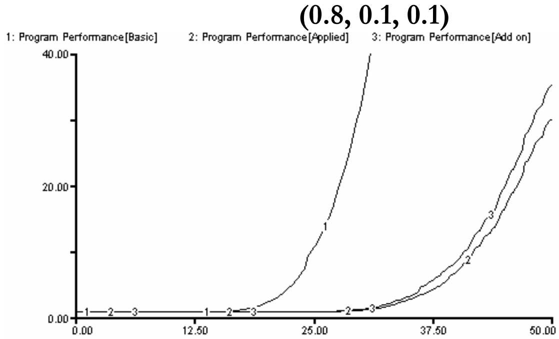
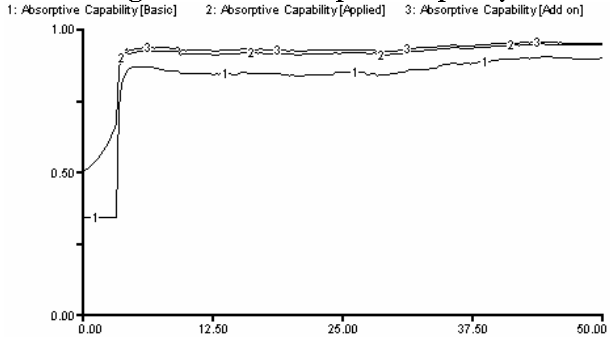


Figure 10-b. Program Performance (0.8, 0.1, 0.1)

Both the above two figures and Fig. 10-c below represent foundational, application, and add-on technologies respectively. Unlike that of other technologies, innovation of foundational technologies occurs continuously. As the technological development graph shows, foundational technologies have a fast rate of growth. Application and add-on technologies, however, create delays in technological innovation. The reason is that the level of foundational technologies, which in turn affects the growth pattern of application and add-on technologies, affects absorptive capacity. As Fig. 10-c indicates, in the case of having more priority on basic technology, the absorptive capacity of all technologies keep high level, allowing us to infer from it that innovations in foundational technologies bring about developments of application and add-on technologies.

Figure 10-c. Absorptive Capacity



On the other hand, when coordination factors were set to prefer application and add-on technologies, the following results:

Figure 11-a. Development Patterns (0.1, 0.8, 0.1)

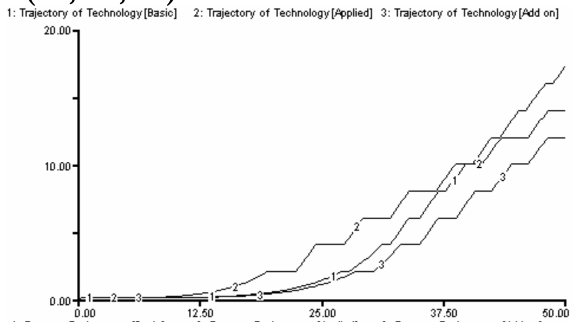


Figure 11-b. Program Performance (0.1, 0.8, 0.1)

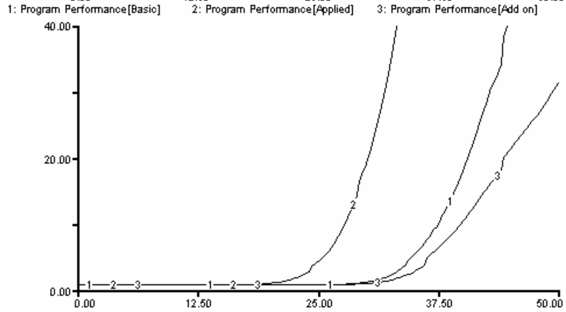


Figure 11-c. Development Patterns (0.1, 0.1, 0.8)

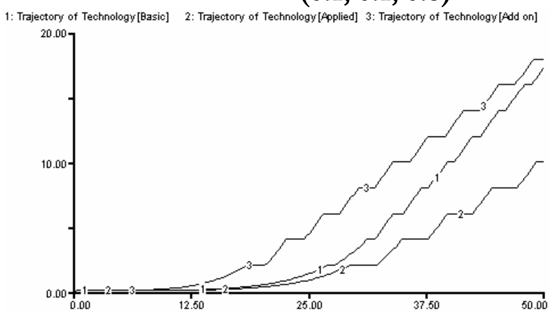
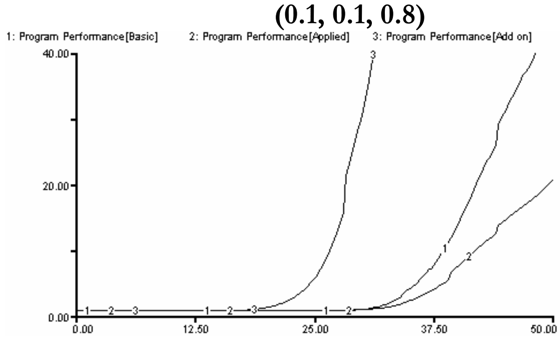


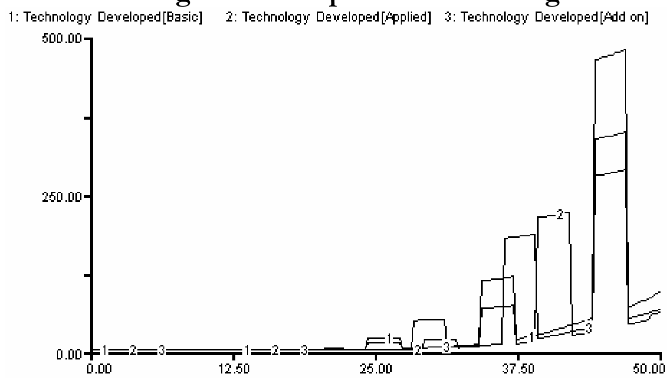
Figure 11-d. Program Performance (0.1, 0.1, 0.8)



The above figures show that technological innovations are retarded, when stage-by-stage growth of application and add-on technologies is remarkable. This finding supports the argument that the traditional Korean policy of favoring application technologies unnecessarily slowed down developments in foundation technologies that are critical in bringing about long-term technological innovations. To avoid an R&D dilemma and to enhance flows and stocks of R&D resources, it is necessary to give priority to foundational technologies.

Two of the reasons for R&D dilemmas were bureaucratic inertia that prohibits participants from canceling some of the inefficient extant projects at the time of R&D budget expansion and myopic investment decisions that emphasize only short-term performance results. To examine the effects of inertia and myopia, we continued to utilize the concepts of capacity building projects and strategic technology development programs. Our assumption is that myopia and inertia occur mostly in the latter, while they decrease significantly in the former. The following is a result of a myopic investment decision:

Figure 12-a. Technological Development due to Program Performance



If we also introduce graphs of program performance for strategic technology development and capacity building programs, they are something like what is shown below,

Figure 12-b. Perfor'ce of Strategic Programs

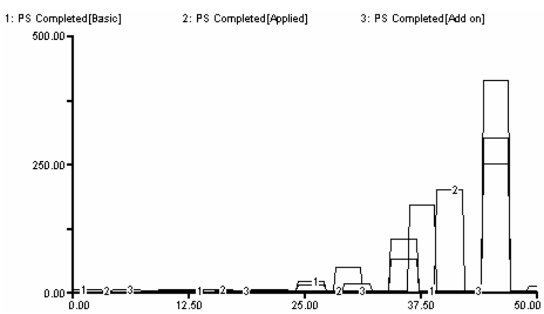
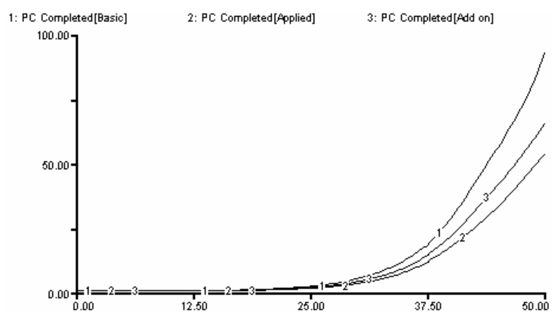
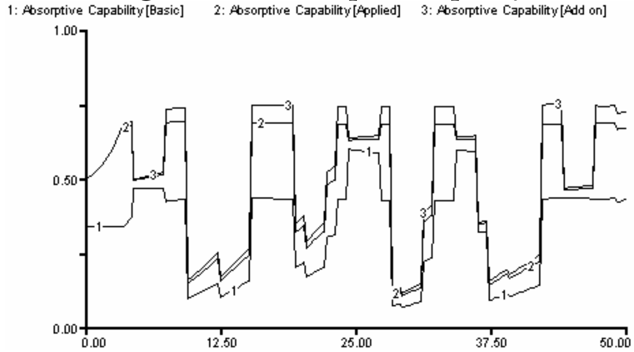


Figure 12-c. Perf'ce of Capacity Prgrms



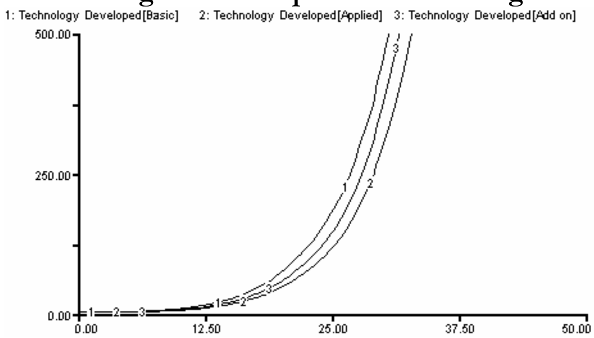
Figures 12-b and 12-c represent the completion of strategic technology development as well as capacity building programs, respectively. Although strategic programs demonstrate a gradual growth with appearance and withdrwal, their growth certainly has delay. This growth limitation fails to produce radical innovations as time elapses. Through Absorptive capacities, which ocillate during the course of evolution, we can explain those results. Since the absorptive capabilities simply appear, not accumulate, the limitation of strategic technology development reinforces.

Figure 12-d. Absorptive Capacity



In effect, R&D investment in strategic technology development programs only generates technologies that have clear growth limitations, as projects cannot produce research results that beef up absorptive capacities. On the other hand, when coordination factors are set to favor capacity building programs, the following graph can be gleaned.

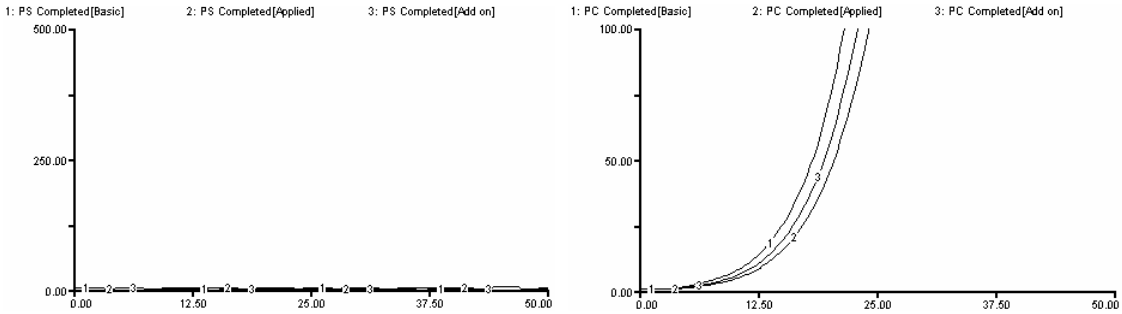
Figure 13-a. Technological Development due to Program Performance



Unlike previous graphs, Fig. 13-a demonstrates an exponential growth in technological development, after R&D projects go through a certain period of temporal delay. If we further divide up technological development into strategic and capacity building programs, the following diagram can be obtained.

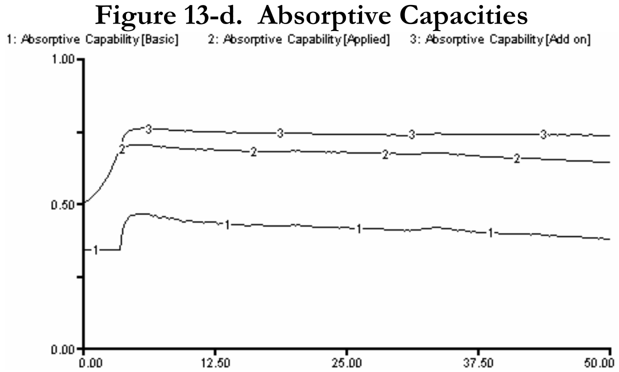
Figure 13-b. Strategic Programs

Figure 13-c. Capacity Building Programs



Although strategic technology development programs suffer from a low level of technological development, capacity building programs produce a remarkably high level of R&D success in terms of technological development, as the above graphs indicate. This means that capacity building programs have much higher efficiency in technological development than strategically oriented programs. This can be further gleaned from the fluctuations of its absorptive capacities. As Fig. 13-d indicates, absorptive capacities increase from the 30th stage when capacity building programs experience exponential growth. Especially, we can affirm that the absorptive capacity for application technologies leads to enhanced capacities in developing application technologies.

Figure 13-d. Absorptive Capacities



In sum, we can confirm that myopic R&D decision-making causes all sorts of errors by focusing only on short-term R&D performances, without taking the importance of absorptive capacities into consideration. Therefore, R&D investments must put absorptive capacities into its formulae.

Having discussed the impacts of types of technologies (i.e., foundational, application, add-on) and patterns of programs (i.e., strategic technology development, capacity building) on short term and long-term R&D performances, we can now analyze the impact of researcher attitudes on R&D performances by changing initial budget size. The following graphs are possible, if we set the proportion of R&D budget on GDP at 0.1%.

Figure 14-a. Program Performance

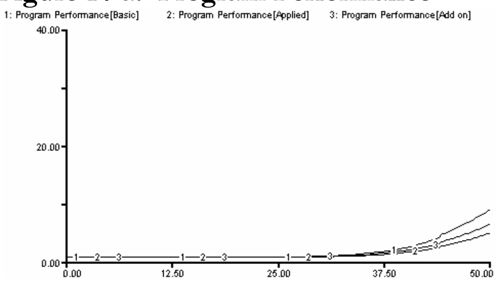


Figure 14-b. Slack Resource

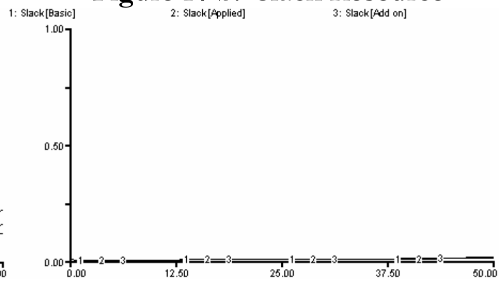


Figure 14-c. Confidence in Getting Support

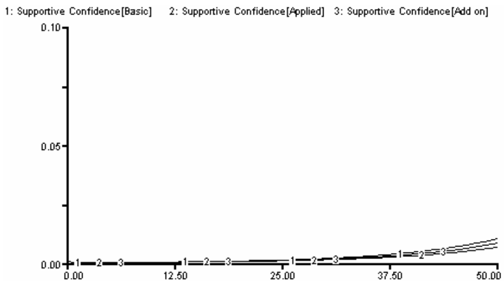
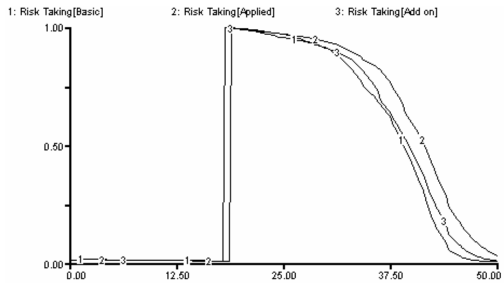


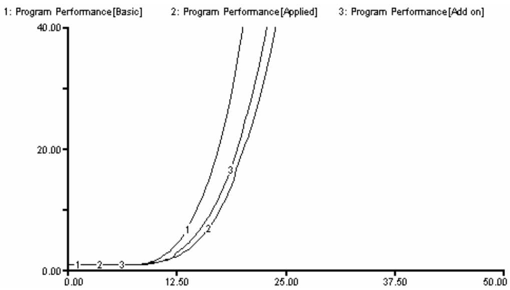
Figure 14-d. Tendency of Risk Taking



The above results show that program performance increases after a certain initial period of delay. Though we believe that the slack resources prompt researchers to take a risk taking posture, slack resources have any effect on risk propensity of researchers so do program performance. The continuous technological development, therefore, is an indication of how confidence, gained by researchers through support from the invetment, was important in bringing about the result.

However, when the beginning R&D investment proportion was set at 3%, slack resources do not contribute to R&D performances drastically as shown in Fig. 15. This means that researchers' confidence or ability rapidly decreased, although slack resources protracted their risk-taking postures.

Figure 15-a. Program Performance **Figure 15-b. Slack Resources**



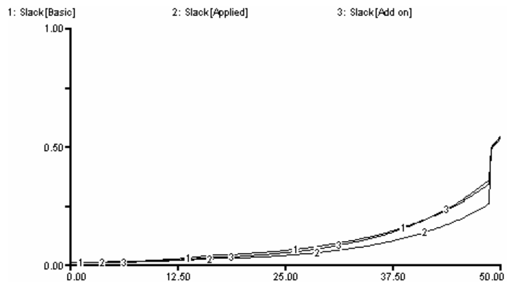
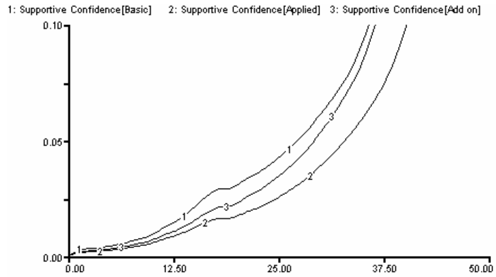
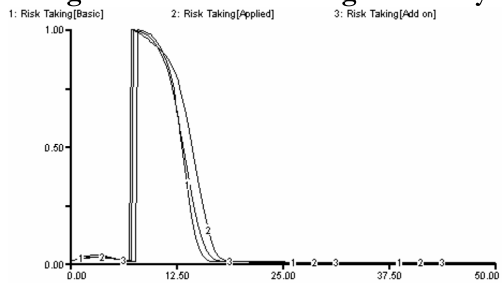


Figure 15-c. Confidence

Figure 15-d. Risk Taking Tendency





In effect, it is found that slack resources would not always result in researcher efficacy. Expanding the funding size to motivate researchers would only lead to other types of inefficiencies. Having discussed the theoretical significance of types of technologies, patterns of NIS strategies, and slack resources in affecting R&D performance in the Korean context, we lastly suggest some policy implications.

Conculsion

Among OECD countries, it is taken for granted that technological innovations play core roles in economic development. These countries are trying to reform the role of the state, so that it can support quick and efficient processes of specialization in the area of new knowledge creation, in addition to providing both short and long term plans for R&D development (Marceau, 2002). The Korean government has continued to play the role of carrying out comprehensive coordination since 1999 for prioritizing R&D investment decisions for the NIS programs. That year coincides with the time when the Korean domestic stock market was invaded and inundated by mad technologies and experienced the subsequent fall of the so-called “dot.com” stocks in 2000.

Our short empirical study suggests that the lack of long term government plans for developing foundational technologies in Korea invited such an economic disaster caused by dot.com companies. We argued that investment decisions had suffered from some visible dilemmas, mostly due to myopia and bureaucratic inertia. Science and technology are closely related to the NIS budgeting process (Makeig, 2002). This means that social prioritization of different types of technologies is critical in determining what kind of technological level a society can achieve. For instance, the Korean case shows that universities are mostly carrying out R&D on foundational technologies, whereas corporations focus mostly on application or add-on technologies. What can we do to find out an optimal prioritization ratio?

Given that NIS has to be continued, and the role of the state has to be strengthened, in part to resolve dilemmas surrounding R&D investment decisions, we suggest that the PBB must continue to coordinate the investment decision-making process in consultation with other participants. In addition, our simulation results found the following possibilities to ameliorate the Korean situation. First, although investment expansion in application and add-on technologies can bring about quick results, it is much wiser to increase investments in foundation research projects in order to obtain long-term scientific and technological competitiveness and to speed up technological developments. Second, we could identify that short term and concentrated financial support for strategic technology development programs engenders all sorts of problems and side-effects, because it often disregards the importance of capacity building programs and their ability to beef up absorptive capacities for most R&D institutes and participants. Strategic programs were also found to provide the initial seeds for commencing a whole vicious cycle of continuous reduction in investment effects. Finally, we found out that new policy leverages must take the dynamic process of R&D decision making into consideration to resolve various dilemmas detected at various stages in the dynamic decision making system.

Future studies on this topic can focus on the side effects and structural delays to identify their overall impact on the NIS and their organizational and dynamic sources. Needless to say, we must acknowledge that this study failed to devise feasible policy leverages that could overcome the different dilemmas present in the current NIS system in Korea. We need further studies to devise a systematic way of providing policy leverages in the resolution of decisional dilemmas in NIS funding.

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