Characteristics of Large-Scale Research and Development Projects: Case Analysis of the Korean Nuclear Fusion Energy Development Project[1)]

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Abstract

This study is intended to analyze the characteristics of Korean science and technology R&D projects involving large-scale facilities and equipment with a focus on the case of the nuclear fusion energy development project. The characteristics of large-scale R&D projects is analyzed depend on this three viewpoints : uncertainty, asymmetries of information and path dependency. The analytical results of this study reveal that Korea's nuclear fusion energy development project failed to consider uncertainty in the early stage of project planning and thus experienced problems. Also, due to information asymmetry, decision makers failed to acquire adequate information on the project, compared with other projects. Lastly, large-scale R&D projects pursed placed too much emphasis on efficiency and thus relied on a small number of experienced researchers for project implementation.

Keywords: large-scale R&D, uncertainty, asymmetries of information, path dependency, nuclear fusion energy development

1. Introduction

1.1 Background

Since the 1990s, Korea has been involved in large-scale R&D projects such as space, nuclear fusion energy and icebreaker development projects requiring large-scale facilities and equipment. Previously, Korea's R&D projects were conducted solely to accommodate industrial requirements. However, the increase in national R&D investment funding and the growth of R&D capability has resulted in an increasing number of large-scale, long-term R&D projects. Korea's large-scale R&D projects have been promoted in a different process compared with those in developed countries, which were focused more on producing achievements in basic and theoretical research. Rather than commencing with basic and theoretical research and then moving to research and development using large-scale facilities and equipment, Korean R&D projects tend to make investment in the construction of large-scale facilities and equipment first. Examples include the development of the Korean space launch vehicle 'Naro' through technology cooperation with Russia and

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development of the next generation superconducting nuclear fusion device without a solid foundation in nuclear fusion R&D.

Korea chose an approach focusing on achieving final missions in large-scale R&D projects to narrow the gap with developed countries. This approach has a object to obtain the advanced scientific and technological capabilities of developed countries within a relatively short period of time, which have been developed over a long period of time. But, after Korea failed in launching 'Naro 1' in Aug 2009, an increasing number of of Koreans began to raise doubt concerning the country's approach to large-scale R&D projects and paid increasing attention to the relationship between an approach focused on achieving final missions such as the launching of satellites or building nuclear fusion experimental device and the country's actual scientific and technological capabilities.

Although Korea's large-scale R&D projects have been conducted through different approach compared with those in developed countries, there are a relatively small number of studies conducted on such characteristics. Existing studies, which have focused on case studies of developed countries, succeeded in suggesting common characteristics of large-scale R&D projects but failed to analyze the characteristics of technology follower countries such as Korea. As a matter of fact, much of problems have been encountered in the process of implementing Korea's space launch vehicle development project or nuclear fusion energy development project such as design changes, technical problems and inflationary problems continued to increase the cost or extend the development period. However, systematic research has yet to be conducted on the causes of such problems in Korean large-scale R&D projects. Therefore, it is necessary to take a look at the characteristics of large-scale R&D projects of technology follower countries and their effects on large-scale R&D projects.

1.2 Overview of the Study

This study is intended to analyze the characteristics of Korean science and technology R&D projects involving large-scale facilities and equipment with a focus on the case of the nuclear fusion energy development project. The major characteristics of large-scale R&D projects have been divided into three categories in this study, which are uncertainty, asymmetries of information and path dependency. The characteristics of large-scale R&D projects is analyzed depend on this three viewpoints through the case of nuclear fusion energy development project in Korea. The result of this study is expected to show the characteristics of technology follower countries such as Korea observed in the process of implementing large-scale R&D projects in basic science.

The nuclear fusion energy development project was undertaken to build nuclear fusion energy power plants using fusion energy created through mixing light nuclei such as hydrogen by 2040. The KSTAR(Korea Superconducting Tokamak Advanced Research) which was focused on developing the next generation superconducting nuclear fusion device, and ITER(International Thermonuclear Experimental Reactor projects) were undertaken. The KSTAR project is constructed from 1995 to 2007, which is succeeded in generating plasma for the first time in 2008. In the meantime, the Korea government began to participate in the ITER project in 2007 as a cash and in-kind sponsor with the object of utilizing the results of the ITER project in building a Korean nuclear fusion energy power plant.[2)]

There are high uncertainties associated with the nuclear fusion energy development projects because the performance of large scale facilities or equipment has not yet been proven through experiments,

2) During the period from 1995 to 2009, Korea invested 569.5 billion won in the nuclear fusion energy development project. For the ITER project, after obtaining approval in the National Assembly in 2007, a total of 876.7 billion won is expected to be invested by 2015 and 1,622.1 billion won is expected to be poured into the project by 2040. For the Korean nuclear fusion energy development project, 184.6 billion won is expected to be poured into the first KSTAR operations stage while 728 billion won is expected to be funneled into the project by 2025.

although basic research and experiments have been carried out using small-scale facilities and equipment. Previously, Korea's most large-scale research and development projects have been conducted on subjects that entail much less uncertainty since the scientific and technological performance of those projects has been already proven in developed countries. However, the nuclear fusion energy development project has high inherent uncertainties and the most effective and efficient path to overcome various potential problems can only be known in hindsight. Such high uncertainties and related characteristics of large-scale science research result in asymmetry of information between policy makers and project conductors. Moreover, uncertainty and the asymmetry of information could lead to path dependency in the project implementation process.

2. Concept and Characteristics of Large-Scale R&D Project

2.1 Concept of Large-Scale R&D Project

Large-scale R&D project is refers to R&D implemented with large-scale government funding to achieve the country's technological and strategic objectives in this study.[3] Regarding the project funding size that serves as a basis for determining the boundary for large-scale R&D projects, the feasibility inspection in accordance with the National Finance Act in Korea defines large-scale projects as those granted a budget of at least 50 billion won whereas the provision on the projects subject to government supervision under the National Finance Act defines large-scale projects as those with a budget of at least 30 billion won.[4] However, when the total project budget is over 50 billion won or 30 billion won, large-scale projects tend to be divided into diverse sub-tasks within the project, which is unrelated with each other in the same project.

Large-scale R&D projects can be divided into large complex projects, comprised of several independent sub-tasks all targeting the same strategic purpose, and single projects focused on developing interrelated facilities and equipment for the same strategic purpose. For instance, many different sub-tasks of the space launch vehicle development project are carried out with the ultimate same purpose of launching a satellite into space. Ultimate single-purpose goals tend to be obvious in large-scale projects related facilities and equipment such as space launch vehicles, nuclear fusion experiment reactors, satellites.

Soliciting the appropriate amount of investment from the private sector for large-scale R&D projects is challenging because of uncertainty and difficulty in securing research achievements even though such projects are critically needed for national development. Therefore, the role of government investment in large-scale R&D projects is ever more emphasized.[5] But, careful and thorough planning is required for large-scale R&D projects because of enormous amount of funds are spent over a long period of time and frequent changes are made to project periods or project expenditures by much of reasons, and it is very difficult and costly to adjust or halt project activities in the middle of project implementation. Moreover, large-scale R&D projects may undermine diversity in national science technology development by concentrating scarce national R&D funds in certain large-scale projects.

The above-mentioned issues arising from the implementation of large-scale R&D projects became

3) Kim Tae-Yoo, Lee Jeong-Dong, Lee Jong-Soo, 2002, 「Technological and Economic Feasibility Analysis Methods for Large-Scale R&D Project」, Science and Technology Policy Institute, 2002.
4) Large-scale projects in Article 38 of the National Finance Act (Feasibility Study) refer to 'large-scale projects defined by Presidential Decree' and stipulated in Article 13 of the National Finance Act. The total cost of large-scale projects exceeds 50 billion won while government subsidies exceed 30 billion won. Large-scale projects stipulated in Article 50 of the National Finance Act refer to 'large-scale projects defined by Presidential Decree' and stipulated in Article 21 (Management of Total Project Cost) of the National Finance Act with total project cost reaching or exceeding 30 billion won.
5) Kim Tae-Yoo, Lee Jeong-Dong, Lee Jong-Soo, 2002, 「Technological and Economic Feasibility Analysis Methods for Large-Scale R&D Project」, Science and Technology Policy Institute, 2002.

manifestly obvious in major developed countries' large-scale R&D projects experiences, so-called 'big science', after World War II. At that time, developed countries pinned their hopes that a huge amount of investment funds funneled into science technology development would strengthen their national competitiveness and increased investment in large-scale R&D projects.[6] National funds were poured into science technology development projects, while financial elements such as financial capacity of the country were not adequately addressed. Expected results often did not materialize and the growing burden of science technology budget led to a sharply increasing number of people paying close attention to investment efficiency and transparency in large-scale R&D projects. As a result, evaluation of research performance became increasingly essential for large-scale projects.[7]

2.2 Characteristics of Large-Scale R&D Projects

There are inevitable uncertainties associated with R&D investment and various issues necessarily arise in the process of project implementation. In particular, analyzing potential risks arising from uncertainty and preparing measures to resolve such risks are essential in the preparation phase of large-scale research and development projects since it is difficult to cease or change course after project take-off. Thus, it is necessary to conduct a comparison of various alternatives and determine which one is the best option for the project in the initial planning phase. When such comparisons and analyses are not conducted properly, the government, which drafts project budgets, and the National Assembly, which deliberates on them, are left to make decisions based on the limited information available. In such cases, decisions on project implementation tend to be made predominantly on feasibility analysis and therefore lack substantial consideration of efficient implementation methods for achieving the same goals and results.

In most cases, the uncertainties of large-scale R&D projects result in changes in project periods and budgets. Table 1 shows major Korean large-scale research and development projects that have experienced changes in project cost and duration. In case of the space launch vehicle development project, which intended to launch a small satellite, 'Naro 1,' into space, the total project budget increased from the initial 359.4 billion won to 502.5 billion won due to the expanded scope of international technology cooperation. In the KSTAR construction project, which was initially planned to be completed by 2007, project cost soared from 150 billion won to 309 billion won and underwent recurring period changes due to technological problems, design change, inflation and process delays. Moreover, in the case of the communication, oceanic and meteorological satellite development project, the project budget likewise nearly doubled from 116.3 billion won to 130.9 billion won through the process of calculating insurance premiums. All of the above-mentioned cases reveal that there are high uncertainties and the subsequent difficulties in project management associated with implementation of large-scale R&D projects, unlike other general projects with less uncertainty.

3. Analysis Perspective on Large-Scale R&D Projects

Large-scale R&D projects share characteristics such as uncertainty, asymmetry of information and path dependency. Among these, uncertainty is related to difficulties in predicting project results, finance requirements and project schedule.[8] Asymmetry of information is derived from the intrinsic uncertainty of large-scale R&D projects and often results in

6) Bush, V. (1945). Science: The Endless Frontier, Charter Document for the US National Science Foundation. Government Printing Office, Washington, DC.
7) Price, A. & Reeve, N. (1998). "Evaluation of public investment in R&D - Toward a contingency analysis". in OECD (eds.). Policy evaluation in innovation and technology: toward best practice. OECD, Paris.
8) Kline, S. & Rosenberg, N. (1986). An Overview of Innovation. in Landau, R. & Rosenberg, N. (eds.). The Positive Sum Strategy: Harnessing Technology for Economic Growth, National Academy Press, pp. 275~305. ; Mytelka, L. K. & Smith, K. (2002). Policy learning and innovation theory: an interactive and co-evolving process. Research Policy. Vol. 31, pp. 1467~1479.

Table 1 Changes in project cost and project period for large-scale R&D projects

(Unit: Billion won)

	Change	Year	Total Project Cost		Project Period		Reasons for Change and Details
			Plan	Change	Kick Off	Completion	
Space Launch Vehicle Development Project	Initial Plan	2002	3,594		2002	2005	
	First Change	2005	3,594	5,025	2002	2007	Expanded scope of international technology cooperation
	Second Change	2007	-	-	2002	2008	Extended development period due to delay in concluding the Korea-Russia Technology Safeguard Agreement
KSTAR Construction Project	Initial Plan	1995	1,500		1995	2002	
	First Change	2001	1,500	2,480	1995	2005	Rising expenses incurred by technology glitches, rising exchange rate and process delay
	Second Change	2004	2,480	3,090	1995	2007	Rising expenses incurred by design change or inflation
Communication Ocean & Meteorological Satellite Development Project	Initial Plan	2003	1,163		2003	2008	
	First Change	2007	1,163	1,309	2003	2009	Raising funds for payload insurances & growing technology development expenses

Source: National Assembly Budget Office「Evaluation of Large-Scale Research Development Project – Focused on Nuclear Fusion Energy Development Project」2009.9

insufficient information for rational decision making.[9] Lastly, path dependency is problematic in that policy makers and project conductors rely heavily on previous experiences and practices or on a small number of experienced research experts to solve uncertainty or information asymmetry issues.[10]

Regarding uncertainty, changes in project expense and period resulting from uncertainty of large-scale R&D projects basically stem from the inability to overcome uncertainty issues in the planning phase, which is obvious not only in Korean R&D projects but also in those of foreign countries.[11] In relation with information asymmetry resulting from uncertainties, the National Assembly and the government lack information as opposed to the government-sponsored research institutes, universities and enterprises in the relevant field. As a result, information asymmetries might arise in the process of budget formulation in the National Assembly or government agency and inhibit rational decision making. As for path dependency, large-scale R&D projects may rely heavily on a small number of experts in the field. In particular, science technology R&D projects are complex in nature and require experts and thus the details of the project are rarely known to those external to the project. In addition, project conductors may prefer experienced

9) Acosta, Manuel. & Coronado, Daniel. (2003). Science–technology flows in Spanish regions: An analysis of scientific citations in patents. Research Policy, Vol.32, Iss.10, No.8, pp. 1783~1803; Metcalfe, J. S. (1995). Technology systems and technology policy in an evolutionary framework. Cambridge Journal of Economics, Vol.19, pp. 25~46.

10) Dosi, Giovanni. (1988). The nature of the innovative process. in Giovanni Dosi. (eds.). Technical Change and Economic Theory. Ch.10, pp. 221~239. ; Malerba, F. (2002). Sectoral systems of innovation and production. Research Policy, 31, pp. 247~264. ; OECD. (2005). Governance of Innovation Systems. Vol.1, Synthesis Report. ; Song Wi-Jin. (2006).「Technology Innovation and Science Technology Policy」, Renaissance.

11) The expenses of the LHC (Large Hadron Collider) project undertaken by CERN (European Organization for Nuclear Research) totaled 3.2 ~6.4 billion Euros (including construction, maintenance and experiment costs). When the LHC project was approved in 1995, the construction and experiment costs were expected to be 2.6 billion Swiss francs and 210 million Swiss francs respectively. However, expenses continued to rise and an additional 480 million Swiss franc was consumed in 2001 and the construction period had to be extended from 2005 to 2007 due to the growing financial burden.

experts for project implementation to lower the risks and enhance the efficiency of facility and equipment development throughout the process. In technology follower countries like Korea, which lack scientific knowledge and expertise, research experiences and available human resources and facilities for project implementation, path dependency can be even more obvious.

4. Case Analysis of Korea's Nuclear Fusion Energy Development Project

4.1 Characteristics and Current Status of the Nuclear Fusion Energy Development Project

Nuclear fusion refers to a phenomenon in which two light nuclei combine to form a heavier nucleus in a high energy status.[12] When the two nuclei combine to form one nucleus, overall mass is reduced and the reduced mass is converted into kinetic energy, generating nuclear fusion energy. Nuclear fusion includes all forms of energy created in the nuclear fusion process, which is identical to the sun's nuclear fusion reaction for generating energy. That is why nuclear fusion energy facilities are dubbed 'artificial suns'.[13]

Experimental research in nuclear fusion energy has so far succeeded only at the laboratory level and no research or experiments have been conducted to examine the commercial viability of this technology. Therefore, it is expected that many benefits may emerge when R&D projects are conducted successfully. However, they are many risks and uncertainties involved in such projects. Nuclear fusion energy projects to examine the commercial viability require massive investment. Despite high expectations placed on the commercial using of nuclear fusion energy, only the few counties are able to afford the large investment required for project implementation.

4.2 Characteristics of the Nuclear Fusion Energy Development Project

4.2.1 Characteristics Arising From Uncertainty

The nuclear fusion energy development project, being a large-scale R&D project in the science technology field, entail much uncertainty and require massive investment over a long period of time. Therefore, it is necessary to estimate with reasonable accuracy the scale of funding for this R&D project and draft response manuals for managing anticipated problems before implementing the project. However, Korea's nuclear fusion energy development project has been promoted without thorough preparation to uncertainty. The case of the ITER project in Korea shows us these problems.

In the case of the ITER project, changes to the overall ITER project budget due to design change and the subsequent increase in country contributions are discussed from the beginning phase of project in the meeting of ITER Board of Directors. As a result of the ITER Board of Directors in July 2010, the duration of ITER project is extended for another 2 years and the budget is increased 28.1%.

The ITER project is funded by general accounts and both the nuclear energy and electricity industry development funds. In phase 1 of Nuclear Fusion Energy Development Plan, when ITER project was approved by the National Assembly for implementation, the plan was to raise funds for ITER contributions through the electricity industry development fund during the period from 2008 to 2011 but no plans were specified for the period after 2012. What's worse, there are no concrete plans on fund raising when the ITER project needs additional funds. As a result, the government has to improvise stop-gap solutions when the need arises.

In addition, the ITER project was calculated to consumer 876.8 billion won at the time it was

12) Clause 1 Article 2 (Definition) of Nuclear Fusion Energy Development Basic Act: "Nuclear fusion refers to a phenomenon in which two light nuclei combine to form a heavier nucleus." Clause 2: "Nuclear fusion energy refers to all types of energy generated through a nuclear fusion process."

13) Ministry of Education, Science and technology,「Research on Nuclear Fusion Energy Development Basic Plan」, 2007. 7.

approved in the National Assembly. However, the ITER project consumed an additional 8.8 billion won due to deterioration in the exchange rate since its kick-off in 2006. Korea's in-kind contribution to the ITER project was estimated based on a won-euro exchange rate of 1,200 won but the continual worsening in the exchange rate forced the country's contribution to rise to 6 million in 2006, 300 million won in 2007 and 3.1 billion won in 2008 when the actual contribution was paid to the fund. Korea bears the additional burden of 5.3 billion won compared with the initial plan when the won-euro exchange rate was estimated to be 1,792 won per euro in 2009.

Considering that the amount of cash contribution grows every year depending on plans, Korea's cash contribution to the ITER project is projected to increase sharply compared with the initial plan. The increase in the amount of contributions to the ITER project resulting from exchange rate fluctuations is the one of the problem that can be anticipated in the early phase of project planning and implementation when considering the previous experiences of project cost increases. However, the Ministry of Education, Science and Technology failed to plan financial requirements proactively or provide additional funding to offset foreign exchange loss using direct cost savings and accrued interest as of 2009 budget.

Increases in the ITER project budget are attributable to both design changes undertaken to solve technological issues and the worsening exchange rate. Although the nuclear fusion energy development project continued to experience project budget increases and design changes, exchange rate fluctuations and technological issues were well anticipated in the case of the ITER project. Yet, little effort was made to reflect the anticipated risks in the mid-to-long term budget formulation process. As a result, various finance factors were not analyzed thoroughly to reflect uncertainty in the large-scale R&D projects, which led to inefficient R&D investment allocation.

Large-scale research and development projects such as a nuclear fusion energy development project require massive investment and continue to require additional funding over the course of project implementation. Thus, it is necessary to consider various factors in the budget formulation process before initiating project implementation. Although the ITER projects implemented under the Basic Plan on Nuclear Fusion Energy Development are conducted based on each specific project plan, no possible risks are projected in advance.[14)]

As a result, the nuclear fusion energy development project is being carried out without systematic preparation for potential risks associated with the implementation of the ITER projects and has been relying on stop-gap solutions to cope with problems such as the rise in project expenses. For future risks, the nuclear fusion energy development project has no other choice but to resort to stop-gap solutions. To tackle such chronic problems associated with project implementation, Korea needs to determine those risks intrinsically associated with large-scale R&D projects and develop measures to address them prior to launching such project..

4.2.2 Characteristics Arising From Information Asymmetry

It is difficult for non-experts to acquire information on the nuclear fusion energy development project due to its highly specialized and complex nature, which may result in an asymmetry of information between project conductors, policy makers and the many other stakeholders in its implementation. Adequate information needs to be provided to all stakeholders to ensure efficient project implementation, rational funding allocation and coherent project finance management.

As the nuclear fusion energy development project can bring significant benefits upon successful completion, it is difficult to verify the feasibility of the project based on cost-benefits analysis method. Therefore, policy decision-making based on mere

14) For example, when Korea was involved in the ITER project, its ITER blueprint was based on the research results of the existing facility (normal conducting Tokamak) rather than on the actual facility (super conducting Tokamak).

economic benefits is also difficult. Also, large-scale R&D projects produce ripple effects in diverse fields over a long period of time and thus decision making on project implementation should divorce itself from the simple logic of success and failure and should focus instead on making informed decisions on the optimal approach for project implementation. To achieve this, policy decision making should compare and examine multiple alternatives rather than coming up with a single alternative. In the case of the nuclear fusion energy development project, various project alternatives with similar benefits should be compared to determine the most effective option to achieve project objectives with the minimal amount of investment funding or maximize benefits with the same amount of funding. Stakeholders should examine the best alternative for the nuclear fusion development

There can be various possible scenarios for project implementation: the country can join the ITER project, alternatively, the country can participate in the nuclear fusion energy development project after the ITER project shows some tangible results, the country can make domestic investments in theoretical research and small-scale equipment before the ITER project produces tangible results. Through comparing the above-mentioned scenarios, decision makers can compare the pros and cons of various project methods and project expenses.

In the survey on experts from relevant fields in relation to 'An in-depth analysis report on the joint development project for international nuclear fusion reactor'[15] quoted in 'Feasibility Study on Mid-to-Long Term Nuclear Fusion Energy Research Development Project KSTAR(2007)', researchers at Nuclear Fusion Research Institute responded that the project should be implemented immediately when asked about the right timing for project implementation while experts from other relevant research institutes responded that the project should be launched after 2015 when the ITER project begins to produce tangible results.

One possible alternative to the ITER project, as shown in the survey results, is the one focused on utilizing KSTAR equipment for exercises until the ITER project proves that nuclear fusion energy is commercially viable. Through comparing such alternatives, a feasibility study should be carried out not just on technological aspects but also on expense. Regrettably, the existing feasibility analyses only show half of the problems revealed in the alternatives while the basic plan on nuclear fusion energy development only stresses the necessity for the current alternative and fails to include an in-depth analysis of the viability of each alternative in terms of expense burden on the country.

In the actual implementation process of Korea's nuclear fusion energy development project, no in-depth comparison analyses were made to examine the alternatives suggested by the diverse stakeholders. Such a decision-making process fails to offer opportunities for stakeholders to acquire adequate information through comparing multiple options and may aggravate information asymmetry in the process of implementing large-scale R&D projects.

In addition, ITER project is being conducted through international treaty; the 「ITER Joint Implementation Agreement」 and 「Privileges and Immunities Agreement」 were approved by the National Assembly on April 2, 2007. However, the motion submitted to the National Assembly for ratification included only the content of the two agreements and project funding was submitted in the form of references. After launching the project in 2007, the motion on the extension of the project period was approved in a meeting of ITER's Board of Directors after two years and the motion on the changes to the total project budget is expected to be confirmed in the meeting of ITER's Board of Directors in November 2009.

Although the size of the project budget is not yet known, SCIENCE (2008.6) reported that ITER's design change would compel the project budget to rise by approximately 200 billion won. However, the government did not provide the National Assembly

15) This survey was conducted on a total of 447 experts, including 100 nuclear fusion experts from the nuclear fusion research center and 337 experts from 4 relevant institutions (Korea Electrotechnology Research Institute, Pohang Accelerator Laboratory, Korea Institute of Energy Research, Korea Atomic Energy Research Institute)

with adequate information on the possible changes to ITER's project cost or project period arising from the characteristics and problems inherently associated with the ITER project. Thus, the government is considered not to have made adequate efforts to provide accurate financial information for the National Assembly's deliberation process.

The above-mentioned cases show that information asymmetry can arise in the process of feasibility analysis and deliberation and the anticipated advantages may hide potential drawbacks such as additional costs or risks when no comparison of various alternatives is made and only one plan is put forward for deliberation of large-scale R&D projects.

4.2.3 Characteristics Arising From Path Dependency

Requisite technical expertise, complexity and uncertainty of large-scale R&D projects, i.e. the nuclear fusion energy development project, tend to make project conductors rely on a small number of experts for project implementation, which can result in path dependency. Such path dependency is particularly obvious in the country that lacks a theoretical and advanced research foundation in nuclear fusion like Korea. As a matter of fact, however, the nuclear fusion energy development project needs to attract researchers and experts from many different fields and create synergy effects given the fact that Korea lacks a solid foundation for nuclear fusion energy research and development. By doing so, Korea can lay a strong basis for nuclear fusion energy development and pay keen attention to research on related theories and basic research and cultivation of experts on nuclear fusion which otherwise would have been neglected.

However, analysis of the nuclear fusion energy development project during the period from 2002 to 2008 reveals that the project was led by a small number of expert researchers to minimize uncertainty. Analysis of national R&D projects during the period from 2002 to 2008 reveals that the National Fusion Research Institute took charge of 6 sub-tasks and the Korea Atomic Energy Research Institute and Pohang University of Science and Technology each took charge of 2 sub-tasks for a total of 10 KSTAR sub-tasks since it was inaugurated in 1995. In 2007, seventeen ITER project sub-tasks were conducted by the National Fusion Research Institute and the Korea Atomic Energy Research Institute and, after its construction was completed in 2007, the KSTAR project was promoted as a basic project of the National Fusion Research Institute and thus participation by other research entities was limited.

Analysis of joint research activities in the nuclear fusion energy development project further reveals that the number of joint research studies in the KSTAR project decreased from 8 in 2005 to 7 in 2006 and to 2 in 2007 out of a total of 10 annual sub-tasks. The number of joint research efforts in the ITER project was only 1 out of 15 total sub-tasks in 2007 and 1 out of 17 total sub-tasks in 2008. Overall, analysis of joint research reveals that the nuclear fusion energy development project is concentrated in the hands of the National Fusion Research Institute and a small number of expert researchers.

National R&D projects in the science technology field requiring large-scale facilities and equipment tend to focus on construction and operation of facilities and equipment and rely heavily on a small number of expert researchers to enhance efficiency. R&D projects with inherent high uncertainty tend to be implemented by researchers who have successful experiences in the existing science and technology R&D projects. This is a problem of path dependency in which R&D projects are repeatedly conducted by a network of experienced researchers. This problem arose in the process of implementing Korea's nuclear fusion energy development project because it was too focused on the mission of building facilities and equipment, failed to encompass various research topics on nuclear fusion energy development and thus relied on government-led research institutes that could conduct the pre-ordained mission-oriented project efficiently.

5. Conclusions

This study examines the possible problems that might arise in the process of implementing large-scale R&D projects with the main focus placed on the nuclear fusion energy development project. Those problems include uncertainty associated with investment in research and development, information asymmetry in making decisions for investment and path dependency in implementation. The analytical results of this study reveal that Korea's nuclear fusion energy development project, one of Korea's major large-scale R&D projects, failed to consider uncertainty in the early stage of project planning and thus experienced problems such as increases in total project cost, difficulties in funding. Also, due to information asymmetry, decision makers failed to acquire adequate information on the project, compared with other projects, and conduct a thorough feasibility study of the project. Lastly, Korea obsessively pursued large-scale R&D projects with the main priority on development and construction of large-scale facilities and equipment, placed too much emphasis on efficiency and thus relied on a small number of experienced researchers for project implementation.

When uncertainty is not considered properly, when decisions are made under information asymmetries and when path dependency of relying on past experiences and practices has significant effect on project implementation, the project may not reap expected benefits and advantages. That is because project conductors have to improvise stop-gap solutions to solve diverse problems when they arise in the middle of the project, which can lower the efficiency of project implementation. The need for additional costs may also lower the efficiency of project implementation. The failure to examine the optimal course to achieve the goals of large-scale R&D projects or potential risks may hinder the rational decision making process from identifying the best alternative. Moreover, in the case of large-scale R&D projects in the science technology field, many research entities should cooperate to secure relevant scientific and technological capabilities and to lay a basis for future research and development even when the ultimate goal of project is achieved. Otherwise, considering the project successful becomes dubious.n

The characteristics, which appeared in the process of Korea's nuclear fusion energy development project, are what technology-follower countries often experience while participating in large-scale science and technology R&D projects. Technology follower countries lack scientific and technological experiences, resources and project management skills when compared with developed countries. In particular, when the areas of research involve high uncertainty to the point where even developed countries lack concrete scientific and technological achievements, technology follower countries might show significant limitations in project implementation. Therefore, it is necessary for technology follower countries like Korea to predict possible risks and problems, consider all the possibilities arising from the uncertain nature of the project and strengthen planning efforts before implementation. Moreover, rather than placing excessive emphasis on the efficiency of project implementation, Korea should consider all the possible advantages from project implementation, compare various alternatives and enhance rational decision-making.

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