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Institutional basis for research boom: From catch-up development to advanced economy

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ABSTRACT

Historical best practice emphasizes that the decision for large-scale R&D investment is important to catch-up growth. It is desirable in most developing countries to establish coherence between technological forecasting and science, technology, and innovation policies. This study demonstrates that national foresight has disadvantages in implementing such policies because of insufficient monetized information with discriminant power for investment. To compensate for such disadvantages, a logic model is indispensable, and can be achieved by subsequent foresight at the time of each decision rather than by one-time national foresight. The example of the Korean government emphasizes that decision-making involving consecutive value-based technological forecasting can act as an institutional framework to progress from catch-up development to being an advanced economy. Despite a tradition against aggressive R&D investment in Korea, quantitative ex-ante evaluations with a feasible value chain have given the financial authorities' confidence. This is what has made Korea's research boom possible. If developing or transition countries plan to achieve catch-up growth by expanding R&D investment, the institutional cases in this study will be an important reference.

1. Introduction

In order to understand what technological forecasting (TF)[1] is today, it is useful to delve into its history. During World War II, TF in the United States was highly focused on anything that could affect military affairs (Dryer and Stang, 2013). In that context, it is vital to know how to win a war. After World War II, large TF exercises were carried out in the defense sector and the civil sector under the tension of the Cold War (Missiroli and Ioannides, 2012; Anderson, 2012). TF in the defense sector continued focusing on "strategic" issues related to national survival until the end of the Cold War, where it co-evolved with innovation studies as a navigator for economic growth around advanced capitalist countries (Georghiou, 2001). Capitalist countries had many success stories of technology-push-type innovations coming from dual-use technology (Serfati, 2008; Callois, 2008),[2] but communist countries could not receive such benefits. At the same time, some developing countries began using TF to achieve catch-up growth.

Since the end of the Cold War, economic competition has replaced the confrontation of ideologies, and increased interest in economic growth has become an overarching concern (Dryer and Stang, 2013; Betts, 1997). Developing countries and transition countries have begun looking for future opportunities in technological competency and productivity in order to catch up to advanced capitalist countries. In this case, they may benefit from being latecomers to TF because they have the results of work conducted in advanced industrial economies to draw upon. Contrary to expectation, a successful policy instrument in one country does not always guarantee success in other countries. A science, technology, and innovation (STI) policy, followed without criticism in a developing country, may cause problems (Lee, 2005). Catch-up growth has not been achieved in many countries, with the exception of a few successful countries such as South Korea, Taiwan, and Japan. Accordingly, developing countries should consider their inherent contextual environment comprehensively before imitating internationally shared success stories.

Catch-up growth is considered a question of relative speed in a race along a fixed track. Technology is understood as a cumulative unidirectional process (Perez, 1988). The speed of progress on the track has been uneven, with some catching up rapidly, while others lag behind. Large-scale investment can explain this difference in catching up in the creative imitation stage and the innovation stage (Perez and Soete, 1988; Lee and Lim, 2001). The case of Central America, unsuccessful in terms of catch-up economics, emphasizes that, in the short term, a lack of funding and weak national commitment to innovation systems are important as a source of social and economic development (Padilla-Pérez and Gaudin, 2014). Based on that historical perspective,

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[1] In this study, technological forecasting, futures studies, and foresight are considered elements in the same continuum under the label of TF.

[2] Dual-use items are products and technologies normally used for civilian purposes, but which may have military applications. Global positioning systems, rocket technology, the internet, and nuclear power technology are typical examples.

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the decision to embark on large-scale research and development (R&D) investment is important because it can create a shared vision from TF to be implemented as an STI policy.

Among various success stories, Korea deserves special mention in using TF as a developing and transition country, because it has been one of the most successful latecomer economies to achieve rapid economic growth and is approaching the ranks of advanced economies. Korea has recently become one of the world's most research-intensive economies by investing 4.29% of its gross domestic product in R&D (Noorden, 2016). The reasons for its success, enabling such aggressive R&D investment, can offer guidance to developing countries suffering from a lack of resources and investment. The high correlation between the characteristics of national foresight studies and the Global Innovation Indicator (Meissner, 2012) deserves attention too. This high correlation implies that the innovation planned using TF is a key factor in Korea's success in catch-up economics. The divided national state of Korea also drives Koreans to keep and to improve policy instruments for developing countries, because successful unification depends on the catch-up growth of North Korea.

The remainder of this paper is structured as follows. Section 2 reviews the background of the institutional basis of the large-scale R&D investment in the context of Korea's STI policy. The methodological approaches are presented in Section 3. Three hypotheses are demonstrated by means of a statistical analysis in Section 4. Section 5 introduces and discusses the case studies, and the final section concludes the paper and suggests areas of possible future research.

2. Background

2.1. Coherence between TF and an STI policy

Although the notion of generations in innovation (Rothwell, 1994; Dodgson et al., 2005) and foresight (Miles, 2008; Reger, 2001; Georghiou, 2001; Tegart and Johnston, 2004; Schlossstein and Park, 2006; Linstone, 2002) have co-evolved, there has been a recent decoupling of these trajectories. The misalignments with innovation, as well as the emerging complexities in foresight explain this decoupling (Andersen and Andersen, 2014; Barré and Keenan, 2008; Weber et al., 2009), which can be classified into coordination failures, communication failures, market failures, and political failures (Pietrobelli and Puppato, 2016). These failures are all evident in developing countries, depending on their stage of development (Rodrik, 2000; Tavares and Wacziarg, 2001; Chan and Daim, 2012). A strong link and coherence between TF and STI policy in developing countries can be achieved by private sector involvement (Hausmann et al., 2008; Hausmann and Rodrik, 2006), a well-organized institutional basis for STI policy with the long-term benefits of TF (Crespi et al., 2014), and linking with global value chains (Pietrobelli and Puppato, 2016). Cumulative empirical studies on catch-up development have revealed that choosing the correct technology or standards and creating initial markets are crucial to successful leapfrogging (Lee, 2005).

If a country tries to implement these practices, a logic model (Jordan, 2010; McLaughlin and Jordan, 1999) will help to justify how the outputs from TF can reduce these substantial risks by mapping values from R&D programs (Kingsley and Melkers, 1999). The structure of many policies can be modeled by logical flows. For example, STI policies can be formulated by a logical flow such as a global value chain (Kexin et al., 2015), a global production network (Ernst and Kim, 2002), or a supply chain (Eksoz et al., 2014). In most cases, TF can formulate a logical basis for implementing an STI policy. If certain policy parameters are adjusted when formulating the policy, the policy can be recognized as being persuasive, with high enforcement power. Tinbergen's (1952) process is convenient to formulate a quantitative policy, and a prospective cost-benefit analysis may be an ideal form.

2.2. The organizational system for STI policy in Korea

STI policies have been studied using diverse approaches (Lundvall and Borrás, 2005; Elder and Georghiou, 2007; Cimoli et al., 2005). Among them, the perspective of Lundvall and Borrás (2005) can be useful to understanding the organizational system for STI in Korea. They argue that STI policies have instruments that are better suited to promote specific areas (i.e., science, technology, or industry), but that their design and implementation should follow a systemic strategy. Because the most important activity of a science policy is basic science, the relevant actors in the science policy are universities and research organizations. Technology policies emphasize the links between science and industry, while innovation policies focus on an industrial policy that influences the process of innovation.

The STI policy in Korea is organized around many ministries engaged in policy formulation, implementation, and evaluation. Among them, the Ministry of Science, ICT,[3] and Future Planning (MSIP) and the Ministry of Trade, Industry, and Energy (MOTIE) are essential because they account for more than 60% of total public R&D expenditure. The MSIP's major roles are the science policy and technology policy. The MOTIE deals with the technology policy and innovation policy. The Ministry of Strategy and Finance (MOSF) is also involved in the STI policy in terms of budget allocation. The Korea Institute of Science and Technology Evaluation and Planning (KISTEP) supports the MSIP and the National Science and Technology Council (NSTC) in coordinating and evaluating national R&D programs, as well as the MOSF in allocating R&D budgets.

2.3. The institutional basis of large-scale R&D investment in Korea

The preliminary feasibility study (PFS), a specialized version of *ex ante* evaluations for the Korean government, was introduced in 1999 to encourage a cautious approach to new large-scale projects by enhancing fiscal efficiency and helping the MOSF. This is performed by verifying the feasibility of projects or programs with budgets of over 50 billion KRW[4] (around U.S. $50 M) and governmental burdens over 30 billion Korean won (around U.S. $30 M). Two indispensable parts of a PFS are the economic analysis and policy analysis. The economic analysis estimates the demand, benefit, and cost, and then the economic feasibility in order to provide information on "*how much to invest*." The policy analysis determines whether R&D program objectives correspond to STI policy agendas, which are derived from national foresight. Each evaluation item is rejected or accepted, yielding a score between 0 and 1. A final decision on "*whether to invest*" is made by synthesizing the results of the economic analysis and the policy analysis, with the help of the analytic hierarchical process (Saaty, 1990). If the overall scores are less than 0.5, the program is always recognized as unacceptable, and cannot be invested in, by law. The detailed PFS methods are summarized in the general guidelines (KDI, 2008).

The PFS was tried on large-scale R&D investments in 2006, and mandated in 2008. This period, as shown in Fig. 1 (b), corresponds to the middle of South Korea's research boom period (Noorden, 2016). The Korean experience of leapfrogging has resulted in one other indispensable analysis item, namely the technological analysis, which supplements the economic and policy analyses. A technological analysis can help to reduce two substantial risks, namely choosing the correct technology and creating the initial markets, using an R&D logic analysis, technological viability, and overlap possibility. An R&D logic analysis includes the overall framework of logical linkages and rationales for the examined program, based on a logic model aligned with economic values (Jordan, 2010; Kingsley and Melkers, 1999). This analysis

[3] Information, Communications Technologies.
[4] Korean won.

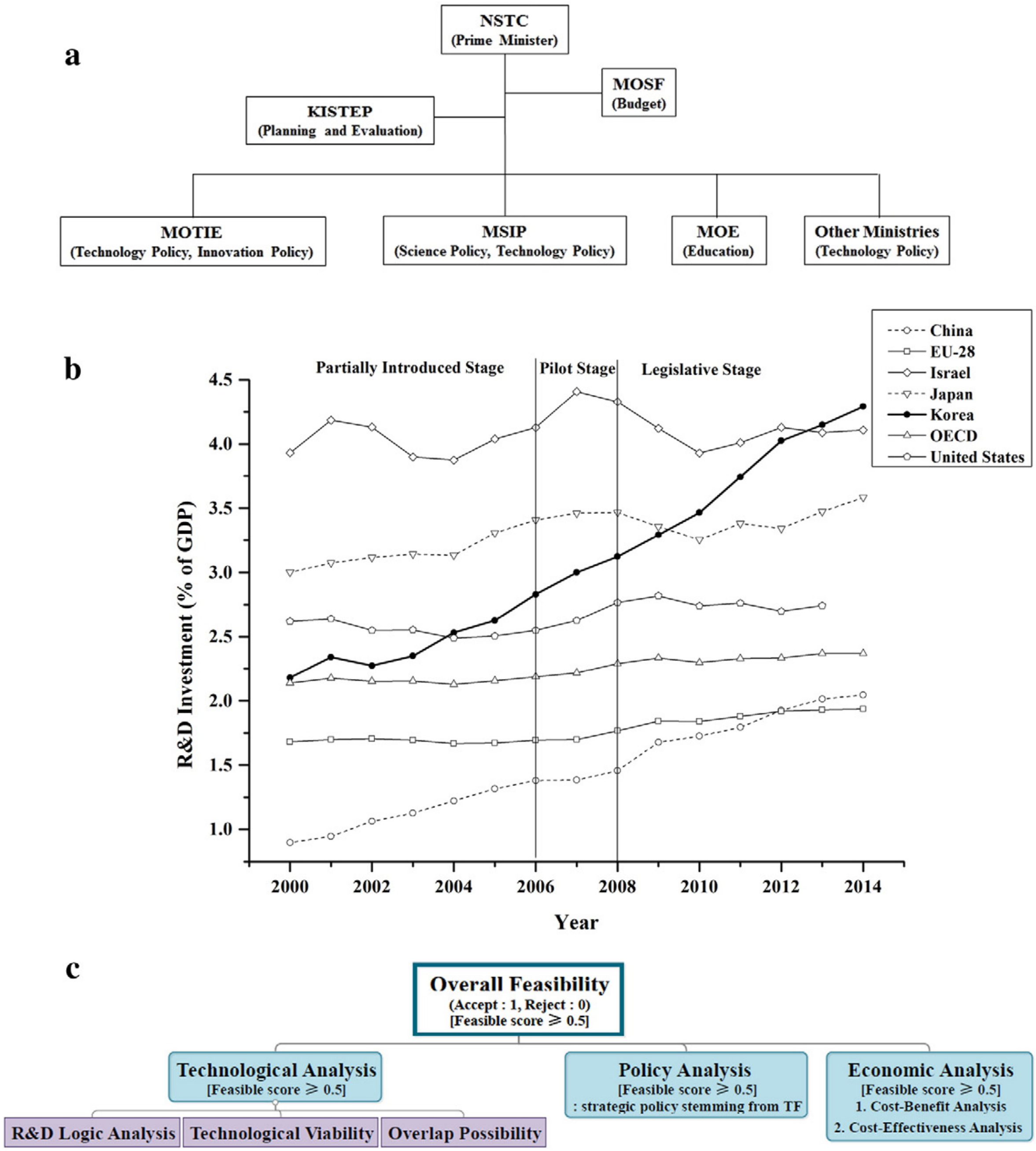

Fig. 1. (a) The Science, Technology, and Innovation System in Korea; (b) Korea's research boom and its relation to PFS on R&D programs; (c) Hierarchical structure for making a decision on R&D investment in the Korean government NSTC: National Science & Technology Council; MOSF: Ministry of Strategy and Finance; MOTIE: Ministry of Trade, Industry and Energy; MSIP: Ministry of Science, ICT, and Future Planning, MOE: Ministry of Education; KISTEP: Korea Institute of Science and Technology Evaluation and Planning.

explains the proposal, why the proposal is valid, how the investment will result in the desired outcome, who the beneficiaries are, and whether the technology is appropriate. It can also be used as a basis for an economic analysis, including information on the risk of creating initial markets. Technological viability includes information on non-competitive and immature budget-consuming programs, and the overlap possibility can identify redundant delivery systems. As a result, a technological analysis is a genuine characteristic of a PFS in R&D programs. It helps us to understand how an STI policy intervenes in the global value chain, and has complex links among the policy agenda, R&D investment, STI activities, and economic values (KISTEP, 2011). The logic model of Tassey (2007) may be a comparable example for a technological analysis of a PFS.

3. Methods

The success factors (Pietrobelli and Puppato, 2016) that achieve a strong link and coherence between TF and an STI policy must be demonstrable in detail before the government will implement the policy. Specific demonstrations provide practical implications, and the PFS of an R&D program is a good example of a test-bed used to verify these implications. This reasoning yields the following hypotheses:

Hypothesis 1. The national TF is less correlated with investment decisions for innovation than it is for an economic analysis or "value chain logic."

Hypothesis 2. "Value chain logic" helps to achieve coherence between TF and an STI policy.

Hypothesis 3. Private sector participation cannot guarantee coherence between TF and an STI policy.

Because the concept of a global value chain is too extensive, we introduce the narrower concept of "value chain logic." Here, value chain logic is defined as the logical flows that have complex links among the policy agenda, R&D investment, STI activities, and economic values. It helps us to understand how an STI policy intervenes in a global value chain. The technological analysis represents the value chain logic in a PFS. Thus, it helps to do the following: 1) identify relations among the needs for the R&D program, opportunities for innovation, program objectives, and STI policy agendas; 2) understand how to generate expected benefits from the examined R&D program; and 3) audit how to align planned activities with program objectives. Therefore, the hypotheses concerning value chain logic can be demonstrated using a statistical correlation analysis on a technological analysis.

For a statistical correlation analysis, the 83 decision-making cases for a PFS are collected from the official website.[5] Every case includes scores[6] for each evaluation item, as well as the result. Thus, there are four scores in each case. The correlation among the four scores is investigated using the Pearson and Kendall correlation coefficients. The Pearson correlation coefficient, denoted as r, is a measure of the linear correlation between two variables. The Kendall correlation coefficient, denoted as τ, is a statistic used to measure the association between two measured quantities. It is often used to test a hypothesis when the dependency between two variables should be examined. After the correlation analysis, the representative cases, which correspond to the organizational systems for STI policies in Korea, are introduced, with discussions of the three hypotheses.

The correlation analysis has advantages. It objectively diagnoses whether there is coherence between TF and an STI policy, provides a quantitative measure of the roles of value chain logic, and can be tailored appropriately according to different situations. Despite these advantages, the method in this work includes two intrinsic limitations: there can be unknown critical success factors, which cannot be captured, and the results will not be the same if the evaluation group is organized by individuals who have extreme opinions.

4. Statistical analysis

The overall feasibility score in each PFS case is composed of three different evaluation items, so two kinds of correlation can be investigated. The first is the correlation with the overall feasibility of investing, as summarized in Fig. 2 (a)–(c), and the second is the correlation among evaluation items, displayed in Fig. 2 (d)–(f). The former refers to the determinants of the investing decision, and the latter indicates the relative relationships among the decision-making factors for the investment.

Since a decision on new, large-scale R&D investment can be understood as a representative signal for implementing an STI policy, the degree of coherence between TF and the STI policy can be measured using the correlation of the overall feasibility of investing. Fig. 2 (a)–(c) shows that the policy analysis is less correlated with overall feasibility. This is evidence for Hypothesis 1, because a policy analysis stems from the national TF. It can also help to explain why there is a gap between TF and implementing an STI policy. Fig. 2 (a) and (c) show that the investment decision depends on the technological analysis and the economic analysis. It demonstrates that lessons learned from successful leapfrogging experiences are considered seriously when deciding on large-scale R&D investment. A policy analysis cannot have any discriminant information on its own, because its scores are higher than the feasibility reference scores.[7] This implies that the primary byproducts of national TF do not have enough discriminant power when implementing an STI policy without any extra activities.

The correlation among evaluation items can show how effectively the technological analysis (i.e. the value chain logic) can strengthen the logical linkages between a strategic policy based on TF and an economic analysis. Although a policy analysis seems to be irrelevant to an economic analysis in Fig. 2 (e), Fig. 2 (d) and (f) shows that the technological analysis acts as a bridge between a policy analysis and an economic analysis. It demonstrates that value chain logic helps to achieve coherence between TF and implementing an STI policy. Therefore, the link between TF and implementing an STI policy can be achieved by subsequent foresight based on the value chain logic at each decision point, rather than by a one-time national TF.

Most policymakers responsible for investment decisions tend to rely on the evaluation of the monetary values, which represents whether the investment is worthwhile. The monetized information and its discriminant power can complement TFs in order to enhance the coherence between TF and implementing an STI policy. In summary, a technological analysis acts as a logical linkage of values between TF and implementing an STI policy by auditing the selection of the correct technology and the business model for creating initial markets.

Table 1 shows that private participation cannot guarantee coherence between TF and an STI policy. However, this does not mean that private participation has no value. This result suggests that the balance point for private participation is more important. In fact, several studies have reported that R&D subsidies from the government can substitute for R&D investment from the private sector, because the players in private sectors tend to make intentional strategic choices in order to maximize their benefit from government support (David et al., 2000; Guellec and Van Pottelsberghe, 2000).

5. Case study and discussion

If classified according to the standards of science policy, technology policy, and innovation policy, the overall R&D programs of the Korean government can be organized in accordance with the mission given to each government department. To facilitate understanding, the types of case study are divided into a science policy, technology policy, and innovation policy.

The STI ministries of Korea have a market mechanism perspective in their policies (Kim and Dahlman, 1992). Thus, the STI policy of each ministry can be understood in terms of supply and demand policies (Elder and Georghiou, 2007). Major supply-side policies may include human resource development policies, technology transfer policies, and domestic R&D policies, whereas major demand-side policies may include export promotion, competition policies, and government procurement.

Among these, the science policy for research excellence has been enforced as a type of human resource and technology policy for accelerated learning, and is implemented as a united body of domestic R&D, export promotion, and government procurement. The cluster approach has been shown in a considerable number of industrial policies as both domestic R&D investment and export promotion. As examples, research excellence, accelerated learning, and the cluster approach are discussed.

Based on the value chain logic of a PFS, its quantitative nature can be illustrated by choosing a collective preference indicator, deducing targets for an economic policy from this indicator, choosing adequate instruments to achieve the targets, determining quantitative values of the instrument variables, and connecting the targets and the instruments and structure of the economy (Tinbergen, 1952).

[5] KISTEP homepage. Retrieved November 26, 2015, from http://www.kistep.re.k/c3/sub2-4.jsp (in Korean).

[6] In the professional analysis of each evaluation item, at least 10 experts participate in scoring, and the extreme scores are eliminated before synthesizing the result.

[7] When the scores of some evaluation items are less than 0.5, it is always recognized as unfeasible.

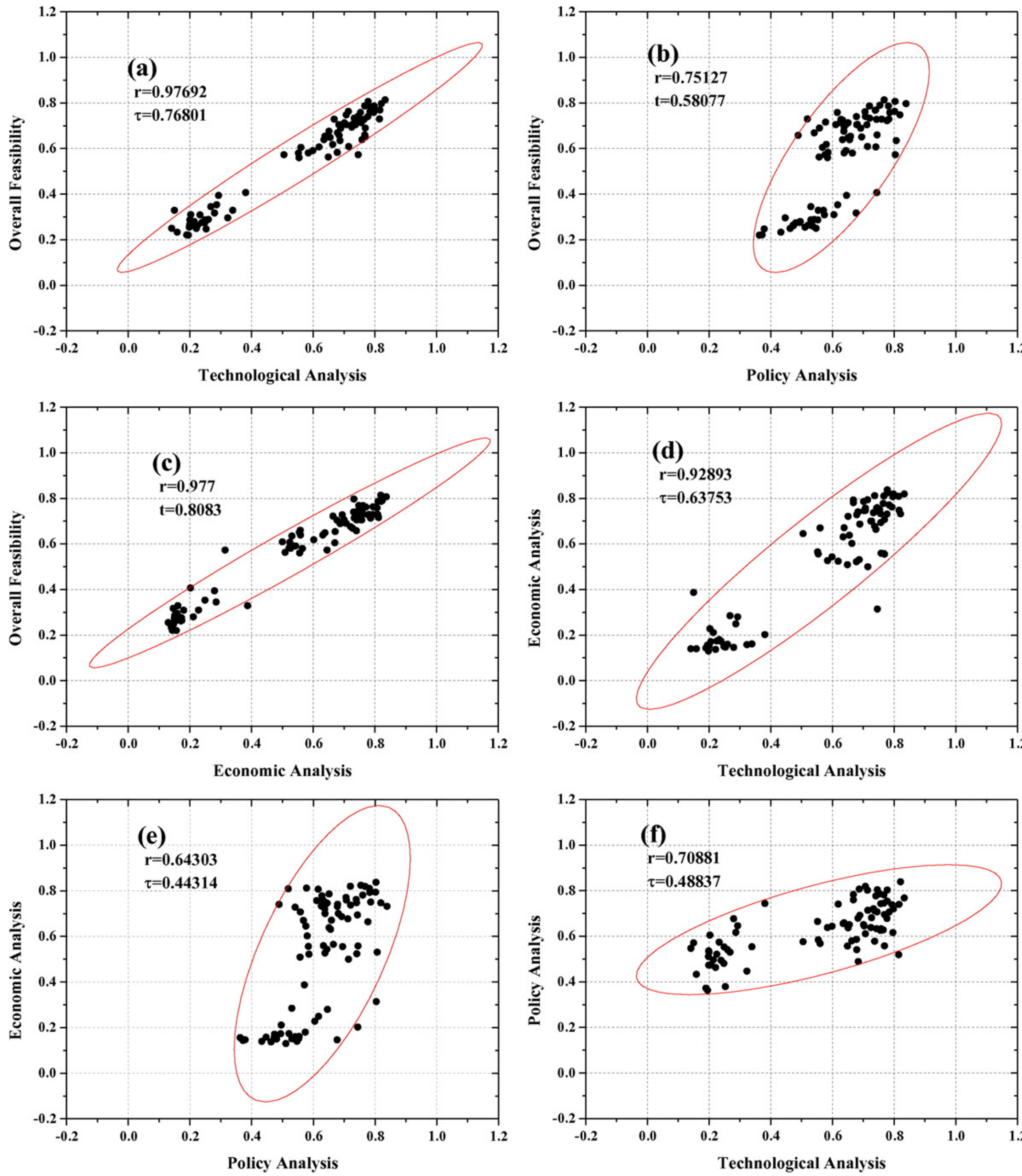

Fig. 2. Correlation analysis on overall feasibility and each item: (a) technological analysis vs. overall feasibility; (b) policy analysis vs. overall feasibility; (c) economic analysis vs. overall feasibility; (d) technological analysis vs. economic feasibility analysis; (e) policy analysis vs. economic feasibility analysis; (f) technological analysis vs. policy analysis.

5.1. Science policy: research excellence

Korea, deprived of natural resources, invested heavily in human resource development to prepare for industrialization. The formation of educated human resource stock enabled Korea to master mature production technologies through an imitative reverse engineering process in the early years. Since the 1990s, the creative imitation stage required universities to produce well-trained scientists and engineers and to have more sophisticated basic capabilities. The government has started many research excellence programs, including the G-7,[8] the 21st Century Frontier, Brain Korea 21, World Class University, Creative Research Center, National Research Laboratory, Science Research Center, and Engineering Research Center.

The PFS on R&D programs for implementing science policies has progressed as an extension of this scientific policy stance. Similar to other advanced countries, bibliometric indicators can be very useful when formulating objectives for a science policy. After investigating

Table 1
Acceptance rate by private participation.

	Without private participation	With private participation	Total cases
Accept	14	42	27
Reject	7	20	56
Total cases	21	62	83
Acceptance rate	66.7%	67.7%	67.5%

[8] This program aims to lift Korea's technological capability to the level of the G-7 countries by the year 2020.

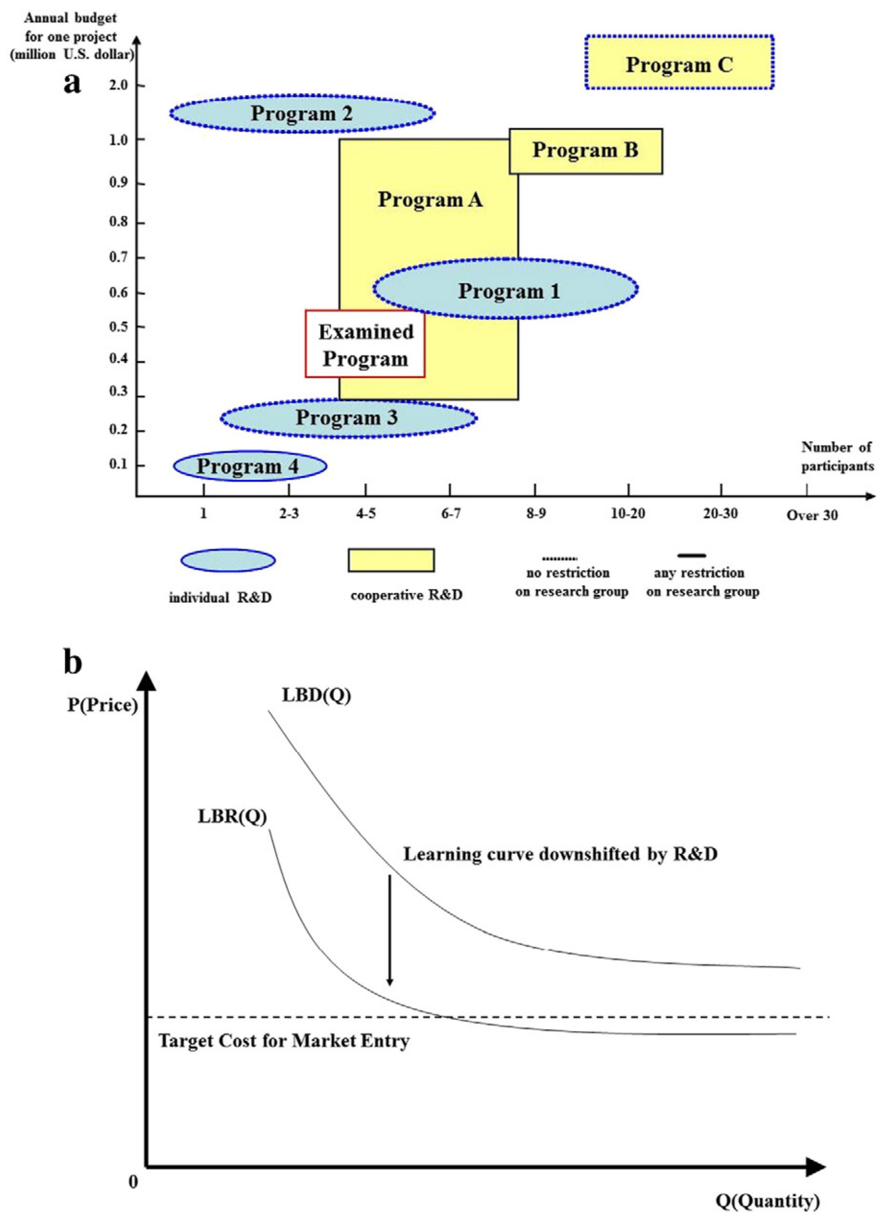

Fig. 3. (a) The overlapping investment landscape; (b) The effect of accelerated learning (LBD: Learning-By-Doing, LBR: Learning-By-Research).

the overlapping investment landscape, as shown Fig. 3 (a), the investment efficiency of an examined R&D program is assessed using the relative measure of cost performance. Table 2 is an example of such a relative evaluation. Then, the government can utilize portfolio methods to enhance its fiscal efficiency.

5.2. Technology policy: accelerated learning

Advanced countries accumulate technological capabilities largely through "learning by research" (LBR), which expands the technological frontier. In contrast, in developing countries, the technological capability is built primarily through a process of imitative "learning by doing" (LBD). The development and strengthening of technological capabilities occur via the process of technological learning, which itself is a costly process, requiring complex interactions among firms and other economic agents within specific institutional frameworks and geographical boundaries (Archibugi and Pietrobelli, 2003; Lundvall et al., 2002; Malerba, 2002; Egbetokun, 2015). Foreign technology transfer plays a major role in accelerating technological learning, because it provides higher tacit and explicit knowledge, as well as useful

Table 2
Typical example of the relative measure of cost performance in an R&D program for a science policy.

	Scientific paper/cost	Impact factor/cost	Patent registration/cost	Technology transfer case/cost	Royalty/cost	Industrialization/cost
Examined program	3.88	12.35	1.57	0.08	0.07	0.10
Program 1	4.85	12.05	4.76	0.25	2.84	0.04
Program A	4.39	10.99	1.23	0.26	0.01	–

Unit: U.S. million dollar.

interactions with foreign suppliers for effective learning. All technological learning targets competitive cost in the market, if the quality is the same level.

A few countries, including Korea, successful in catch-up growth have made a rapid transition from LBD to LBR (Hobday, 1995). Technology policies, as a united body of domestic R&D, exported promotion, and government procurement, help to make this rapid transition. LBR can be achieved in various ways, such as stage-skipping (Winskel et al., 2014), economies of scale, and economies of scope.

Based on an R&D policy, an export promotion policy has been more influential than any other policy tool in forcing Korean firms to expedite technological learning. Export-oriented industries accounted for the majority of foreign licensing and capital goods imports and of R&D investment in Korea. Korean exporters also invested in capacity in excess of the local market size in order to achieve economies of scale. This resulted in crises, forcing them to accelerate technological learning to maximize capacity utilization. Although procurement policies have played a limited role in creating demand for technological efforts, there is room to act for initial market entry related to information infrastructures (Kim et al., 1987), power plants (World Nuclear News, 2015; Wang and Li, 2016), and weapons (Army Technology, 2015; UPI, 2015).

Fig. 3 (b) shows how LBR can result in a more efficient learning curve. Henderson's law of the learning curve (Grant, 2004; MacGillivray et al., 2014) can estimate the unit price for production as a function of the elasticity of cost. LBR can increase the elasticity of cost and cause the original learning curve to shift downwards (Benito et al., 2014). As a result, the target cost for market entry can be achieved easily using LBR. If a large investment is aided by the government, it should be able to occupy a more favorable position in the course of relationship learning (Jean and Sinkovics, 2010; Kane and Alavi, 2007; Wang and Hsu, 2014). Therefore, greater balanced power asymmetry creates an opportunity to move from exploitative innovation to exploratory innovation (Wang and Hsu, 2014). Among various technologies, dual-use technologies (Callois, 2008), which have military applications, but can be used for civilian purposes, provide the opportunity to benefit from economies of scale and economies of scope by enabling various options in the process of design or negotiation. Under the condition of liberalized trade, a stronger and more visible trade-off has been reported between international competitiveness and national defense and security objectives (Blom et al., 2013).

5.3. Innovation policy: cluster approach

Lacking its own capability, Korea had to resort heavily to foreign technology, but relied little on foreign direct investment. Rather, domestic multinational corporations (i.e. chaebols) have developed extensive global networks with foreign firms, which have provided technology licenses, capital goods, and original equipment manufacture orders. These networks have been a major source of technological learning for Korean firms (Lee, 2005). Although these chaebols were independent, without much collaboration or exchanges of knowledge among them, they relied on other diverse firms in advanced countries, such as R&D firms, small technology firms, and other multinational corporations, as sources of new knowledge in the form of embodied technology importations, licensing, co-development, and horizontal collaborations (Lee, 2005). In contrast, each chaebol, behaving like a flagship firm, has brought up and maintained its own network with subcontracting or collaborating firms (Lee, 2005). These networks in Korea are interconnected geographically in a particular field in order to increase the productivity of the companies in the cluster, drive innovation in the field, and stimulate new businesses in the field. These industrial clusters are important to formulating industrial policies.

Although there are differences in specific policy measures according to the changed global value chain, the government favors such industrial clusters, as shown in Table 3. With regard to the demand-side policy, export promotion is still valid. At the same time, domestic R&D policies in past industrial clusters have focused on strengthening the global competitiveness of chaebols, but have recently placed more attention on the competitiveness of the overall industrial ecosystem. The feasibility of R&D investment for the industry cluster can be evaluated using the benefit-to-cost (B/C) ratio. The benefits from R&D investment can be estimated by the probabilistic value added from future target markets, which come from future target markets and the contribution of examined R&D programs in counterfactual situations. As a result, benefits are calculated using the following formula:

$$\begin{aligned} \text{Benefit} &= \text{value added from future target market } (①) \\ &\quad \times \text{contribution of examined R\&D program } (②) \end{aligned}$$

The value added from a future target market can be estimated by the product of the overall size of the future target market and the value-added rate from an input-output table. The contribution of the examined R&D program can also be determined by the contribution of R&D, the success rate of R&D commercialization, and the investment ratio of the examined R&D program, relative to overall similar investment. These uncertain future parameters for estimating benefits can be determined using a widely known method for TF. They are applied in the following order: the statistical estimation, scenario method, and expert judgement. By way of example, TF can help to reduce the risk associated with uncertainty in commercializing technologies (An and Ahn, 2016; Link and Scott, 2010) in this PFS process.

6. Conclusions

The coherence between TF and an STI policy is essential in almost every country, and appears to be especially desirable in developing countries, because many have shown keen interest in catch-up growth, such as Korea and Japan. Based on this historical aspect, the decision for large-scale R&D investment is important because it can create a shared vision from TF to be implemented by an STI policy.

This study demonstrates three hypotheses for achieving a strong link and coherence between TF and an STI policy using cases of investing in large-scale R&D investment in Korea. We conclude that TF has disadvantages in implementing an STI policy because it cannot provide sufficient monetized information with discriminant power for investment. To compensate for these disadvantages, value chain logic is indispensable, and can be achieved by foresight at each decision point, rather than by one-time national TF. In contrast to the findings of Pietrobelli and Puppato (2016), the balanced point for private participation is more important, because widespread market failure, poor institutional development, and scarce coordination of public policies, society, and science in developing countries can result in market players being misaligned with the vision outlined by the TF. An optimal intervention depends on the technology maturity and industrial structure of the country, and can distribute private and public benefits efficiently.

As a result, this institutional basis is important for increasing the coherence between TF and STI policy. The cases of the Korean government emphasize how decision-making involving consecutive

Table 3
Concentration of cluster approach in an industrial policy.

	MOTIE cases (industrial policy)	The cases from ministries other than the MOTIE
Cases including the cluster approach	19	6
Cases other than the cluster approach	14	61
The ratio of cluster approach (%)	57.6%	9.0%

value-based TFs can act as an institutional skeleton to progress from catch-up development to being an advanced economy. Although there is a tradition against aggressive R&D investment in Korea, the PFS has given confidence to financial authorities through rigorous ex-ante evaluations. This is the secret that enabled Korea's research boom. If developing or transition countries plan to achieve catch-up growth by expanding R&D investment, the PFS will become an important reference.

The results of this study are not conclusive, but they do provide challenges for future research. First, an in-depth case study on the PFS should be conducted, because successful catch-up growth can be reproduced in developing countries and transition countries. In addition, applying a PFS to other countries in a tailored way remains a challenge.

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