Exploration of the effects of open innovation policies on national innovation systems through system dynamics simulation: applying the results to Cambodia

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Abstract

Nowadays, the use of purposive inflows and outflows of knowledge to accelerate internal innovation and to expand the markets for external use of innovation has become essential in business strategies and national policies. In addition, the importance of knowledge and technology diffusion requires better understanding of knowledge networks and "national innovation systems". We want to answer this research question: What kinds of effect will occur in national innovation systems (NISs) if different levels of open innovation policies are introduced into NISs? According to literature review, perfect open innovation policies should have three aspects, namely, knowledge and technology production, distribution, and consumption. We build up a causal loop diagram and a system dynamics model to simulate the effects of open innovation policies on NISs and apply the results to the case of Cambodia to develop a Cambodian science and technology master plan.

1. Introduction

Nowadays, no single company, not even the manufacturing giants, can monopolize the knowledge landscape as was previously the case [45]. As a result, the use of purposive inflows and outflows of knowledge to accelerate internal innovation and to expand the markets for external use of innovation has become essential in business strategies and national policies. We call the old approach, which is in contrast to recent situations, closed innovation (CI). According to this approach, successful innovation requires control, and companies must generate their own ideas and then develop, build, market, distribute, serve, finance, and support them on their own [7]. A new approach, called open innovation (OI), is emerging in place of closed innovation. Open innovation assumes that firms can and should use external ideas as well as internal ideas in addition to internal and external paths to markets [7].

The importance of knowledge and technology diffusion requires better understanding of knowledge networks and “national innovation systems” [28]. In the times of knowledge-based economy, open innovation paradigms are applied not only to advanced countries or certain economic systems but also to almost all existing enterprises. Therefore, changing the innovation system of a certain country into an OI paradigm-based system has very important meanings and values. OI relies heavily upon the availability of external knowledge that companies assimilate and integrate into their business and the speed of knowledge distribution from producer to user. However, these open innovation paradigms do not come or be activated by themselves. This knowledge is the result of numerous and often unconnected public policies regarding science, technology, intellectual property (IP), and education within society [8]. The ability of firms to apply OI depends on a large number of external factors, namely, a continuous supply of outside knowledge, highly educated personnel, financial resources, effective legal systems, institutions protecting IP rights, mobile workers, and venture capital (VC). Most of these factors are closely related to a country’s national system of innovation [45].

While being in charge of a task to establish a Cambodian national science technology master plan as the Korea government’s official development assistance (ODA) projects for Cambodia from 2011 through 2013, we have established policies for the activation of OI at the level of the national innovation system (NIS) in terms of the direction and content of the Cambodian science technology master plan. In this study, we intended to obtain answers to the following research problem: How do the country’s policies for improving the openness of national innovation systems affect the country’s productivity and competitiveness? That is, what kinds of effects will occur in the Cambodian NIS if the national innovation system of Cambodia invites high-level open innovation policies into the country? This research problem is premised on two assumptions. The first one is that enhanced openness of the NIS will increase knowledge production in the country through the expansion of research and development investments in the country. This will bring about technical innovation to promote enterprises’ product and process innovation, eventually leading to the improvement of national productivity and the enhancement of national competitiveness. The second assumption is that enhanced openness of the NIS will induce inflows of knowledge and technology from foreign countries or enterprises, leading to the improvement of national productivity and the enhancement of national competitiveness. Here, the enhancement of the openness of the NIS means the enhancement of the degree to which enterprises in the country rely on open innovation. Therefore, an NIS where enterprises in the country mainly rely on CI may be defined as a closed NIS, and an NIS where enterprises in the country mainly rely on OI may be defined as an open NIS. In this study, answers to the research problem were obtained through system dynamics simulations.

To solve this research problem, first, a causal loop diagram and a system dynamics model about NIS which would simulate the effect of OI policy were established through literature reviews of NISs and OI policies.

The practical usefulness of the designed system dynamics model will be tested later using the results of local seminars, interviews, participating observations regarding the Cambodian NIS, and related statistical data for two years.

Next is the effect of the enhancement of the openness of the NIS. The introduction of open policies into the NIS to enhance the Cambodian government’s competitiveness was estimated through dynamics simulations of the NIS system. Then, based on the implication of the results of these simulations, major concrete directions and contents of the Cambodian science technology master plan will be proposed.

In this study, system dynamics simulations used were based on diverse study methods. After the Record of Discussion for the establishment of the Cambodian science technology master plan was signed on June 2011, substantial work began in December 2011, and interviews were conducted six times. In particular, during the period from October 25, 2012 to November 8, 2012, intensive interviews with related persons in industry, academia, research institutes, and government were conducted. During the same period, the capabilities of major parties in the national innovation system and the present state of knowledge production, distribution, and consumption were grasped through intensive participating observations in Cambodia. In addition, in July 2012, the first workshop was held with various Cambodian governmental departments and local administrative agencies to provide an opportunity for participants to analyze the entire existing NIS in Cambodia. Then, in March 2013, the second workshop was held mainly for the Cambodian science technology master plan to form an agreement to and sympathy with the entire contents of the open innovation policy-based Cambodian science technology master plan in Cambodia. Finally, in June 2013, the Cambodia science technology master plan will be reported to the prime minister of Cambodia.

2. Literature Review

2.1 Concepts of the NIS

The concept of the NIS was mainly developed by three scholars: Freeman, Lundvall, and Nelson [11]. As shown in Table 1, common features can be found from discussions in the process of the settlement of the concept of the NIS. Freeman [16] took note of the network of institutions and new technologies made by the network. Lundvall [23] emphasized interactions among elements for the production, diffusion, and use of economically valuable knowledge. Nelson [49] emphasized interactions among organizations that enhance the records of innovation of enterprises in the country, and the OECD [29] focused on the distribution of technology and information [30]. Overall, the creation of innovation performance through the production, distribution, and consumption of knowledge and technology among parties in the country was generally defined as the national innovation system [25].

Table 1
Diverse definitions of NIS.

Researcher	Definition of NIS
Freeman [16]	The network of institutions in the public and private sectors whose activities and interactions initiate, import, modify, and diffuse new technologies
Lundvall [23]	The elements and relationships that interact in the production, diffusion and use of new, and economically useful, knowledge; either located within or rooted inside the borders of a nation state
Nelson [49]	A set of institutions whose interactions determine the innovative performance of national firms
OECD [29]	The national innovation systems approach stresses that the flows of technology and information among people, enterprises, and institutions are key to the innovative process. The measurement and assessment of national innovation systems was centered on four types of knowledge or information flows: (1) *interactions among enterprises*, primarily joint research activities and other technical collaborations; (2) *interactions among enterprises, universities, and public research institutes*, including joint research, co-patenting, co-publications, and more informal linkages; (3) *diffusion of knowledge and technology to enterprises*, including industry adoption rates for new technologies and diffusion through machinery and equipment; and (4) *personnel mobility*, focusing on the movement of technical personnel within and between the public and private sectors.

Source: OECD [29], the contents were revised and supplemented

2.2 Major elements of the NIS and the relationships between the elements

As shown in Table 2, NISs have components of quite diverse natures, depending on the subjects to be analyzed, such as enterprises, state organs, and research institutes. Therefore, NISs having diverse components can be designed depending on the study purposes and content of research. However, because of the definition, and the characteristics of NISs shown in Table 1, NISs related to production, distribution, and consumption of knowledge should be designed. The diverse relationships among the elements of NISs basically have the characteristics of network relations. NIS components have characteristics of networks that are far from single directions or hierarchical structures. In addition, several studies analyzed changes in the time series of NISs, such as Wong [47], Hung and Whittington [19], or Metcalfe and Ramlogan [26].

Table 2
Major elements of NISs and the relationships between the elements.

Research	Major elements of NISs	Characteristics of the relationships between the elements
Metcalfe and Ramlogan [26]	Knowledge and information, markets and enterprise, innovation ecologies, innovation policy	NIS framework for analyzing NIS and competitive process in developing economies
Hung and Whittington [19]	Framing, aggregating, and networking	Three-step strategies of institutional entrepreneurship of Taiwanese IT
Marxt and Brunner [24]	Enabler and supplier, processes, results, further actors, innovative organization	Analyzing NIS of highly developed countries such as Switzerland
Tsai et al. [43]	NIS factors, such as policy kits and regulation, resource release, NIS-supported research institutes; business incubation as an interface of knowledge networking; enterprises factors, such as corporate R&D, tech strategy, tech commercialization, strategic renewal	The co-evolution of business incubation and NIS in Taiwan
Wong [47]	Four types of NIS: Type A—industrial policy mechanism for indigenous technological development-value reducing rents; Type C—industrial policy mechanism to attract FDI for industrialization-value enhancing rents; Type D—industrial policy mechanism for indigenous technological development-value enhancing rents; Type B—industrial policy mechanism to attract FDI for industrialization-value reducing rents	Categorizing Southeast Asia NIS according to rent-seeking and industrial policies
Niosi et al. [50]	Units, such as the number of private firms with R&D facilities, government labs, or universities; flows, such as R&D expenditures in proportion to GDP; performance, such as patents granted per researcher or patents per million dollars in expenditure	Measuring NIS
Chung [9]	Company (networks and knowledge base), university (the accumulation of knowledge) National institutions (pharmaceutical and biotechnology policies)	The configuration of national, sectoral, and technological innovation systems; Taiwanese

		pharmaceutical biotechnology and agricultural biotechnology innovations system
Castellacci and Natera [6]	Innovative capability: international trade, human capital, infrastructure Absorptive capacity: innovative input, scientific output, technological output	The co-evolution between innovative capability and absorptive capacity
Samara et al. [35]	Knowledge and human resource, R&D capacity, product innovation, process innovation, production capacity, product attractiveness, market share, revenues, expenditure on R&D	The impact of innovation policies on the performance of NIS
Guan and Chen [18]	Original inputs, knowledge production process, knowledge commercialization process, final outputs	A conceptual innovation process oriented framework
Kim and An [21]	Amount of R&D, increase in industry by R&D, technology related industry, perceived efficiency of R&D, total amount of R&D	National R&D investment-based NIS construction
Won and Yun [46]	R&D total control ability, R&D investment efficiency, amount of R&D investment, knowledge accumulation, technological innovation, productivity, outcome, national competitiveness	R&D total control ability-based NIS construction

2.3 Discussion of the system dynamics of NISs

On reviewing studies that are the basis of the system dynamics (SD) of NISs, it can be seen that many of those studies have progressed considerably. Representative examples include “The relationship between innovation and economic change” [14], “National level system dynamic model” [15], and “Causal loop in NIS and the problem” [32, 41]. Studies regarding the diffusion of innovation logic and process [33], endogenous technological change [34], or system thinking and organizational learning [36] also formed the basis of systematic thinking and logics surrounding technology and innovation.

Studies such as “Decision Making Process and Administrative Behavior” [37, 38] and “Process of Knowledge Growth” [39,54] related to basic concepts of the SD of NISs in that they dealt with knowledge and technology in terms of processes. Studies such as “Chaos in an Experimental Economic System” [40], “Path Dependence and Dynamics” [42], and “Modeling of Product Development Process” [12] concerned the logical basis of the SD of NISs through economic systems and production processes.

Studies such as “Dynamic Change of Industrial Dynamics” [13], “Economy of Science and Technology” [10], “The Growth Engine from Customer” [4, 5], and “Increasing Returns and Path Dependence in the Economy” [2] can also be the basis of the establishment of the SD of NISs in diverse aspects the dynamics of industries.

Studies such as “Learning by Doing”[1] and “The Cognitive Maps of Political Elites” [3] form the basis of discussion on the SD of NISs in that they elucidate the behavior of parties of the economy at the level of systems.

Most of the studies that analyzed the start of the virtuous circle of growth directly have dealt with the SD of NISs [27]. Studies that analyzed system dynamics, path dependence, and economics of networks can also be directly reinterpreted as studies of the SD of NISs [22]. Recently, system dynamics analysis studies of the impact of innovation policies on the performance of NIS have formed the SD of NISs to analyze the effects of innovation policies using simulations [35].

It can be seen that studies to embody NISs into SDs have proliferated through these diverse discussions. However, there are few common elements of NIS SD modeling and the variety of composition of NIS SDs in terms of the NIS elements that researchers want to analyze.

2.4 Open innovation policies for NIS

Chesbrough [7] models the relationship between NIS and OI when he illustrates how structural changes in the U.S.'s NIS have created a widely distributed knowledge landscape since World War II due to the greater availability of highly educated workers, venture capital, and state-of-the-art knowledge [45]. In fact, the relationships between OI and NISs have quite important effects on policies. Few studies have analyzed these two together because, whereas the former focuses on transfers of knowledge and technology across the boundaries of enterprises as individual firms, the latter focuses on the production, distribution, and consumption of knowledge and technology in each country. Because OI activation at the level of enterprises is an important drive in the enhancement of the productivity of NISs, diverse discussions on the necessity and methods of the development of policies that can activate OI have been raised [20]. Not only OI activation policies for healing market failure but also more active roles of the government for enhancing open innovation at the level of the systems of innovation are required. If enterprises open up their innovation process, they will obtain better results [7]. Similarly, innovation is the result of complex and intensive interactions among various actors, according to Lundvall [23]. That is, lots of similarities between open innovation and systems of innovation models exist [20].

Few policy studies to promote OI have been carried out because policy studies in this area began only recently, as shown in Table 3. As seen in Table 3, policies for enlarging the OI of target NISs are diverse, according to the researchers or research goals. However, there are some common OI policies among three research groups.

Table 3
Policy for open innovation.

Researchers	Policy types or policy areas	Characteristics
Jong et al. [20]	R&D: financial R&D incentives, high-quality IP systems Support standards, supports user innovation Interaction: develop skills, stimulate interaction, Enhance technology markets, use go-betweens Back up clusters Entrepreneurship: support corporate entrepreneurship Access to finance, back up challengers Science: appropriate funding, balanced incentives Focus on excellence, organized diffusion Education: general stimulation, Entrepreneurship education Labor markets: aim for flexibility, Enable knowledge migration Competition: stimulate competition	Two levels of open innovation: firms' open innovation practice and external open innovation conditions that encourage enterprises to practice open innovation
Wang et al. [45]	Cultivating undeveloped technology market Stronger IPR protection supporting efficient flows of knowledge The supply of high-quality labor Eliciting social resources for innovation Benefiting from strong specialization in innovation labor Improving the efficiency of resource allocation Accelerating knowledge flows at low transaction costs Diversifying the networks used in NIS Enlarging the knowledge exploration landscape based on online social networks Knowledge exploitation network which focus on commercialization	Three approaches to NIS: structural, functional, and effectiveness
Chesbrough et al.	Education and human capital development:	Open innovation

[8]	Increase meritocracy in research funding Support enhanced mobility during graduate training Financing open innovation: the funding chain Introduce the funding chain concept Increase the pool of funds available for VC investment Support the formation of spin-offs to commercialize research discoveries A balanced approach to intellectual property Reduce transaction costs for intellectual property Foster the growth of IP intermediaries Promoting cooperation, competition, and rivalry Promote spinoffs from large companies and universities Focus on innovation networks Expanding open government Accelerate the publication of government data wherever possible Utilize open innovation in government procurement Foster commercial application of technologies developed for the government	policies are directly proposed in five categories

The characteristics and essence of OI policies may be established in terms of drawing policies commonly presented in recent studies of OI policies. Those are concurrent between knowledge production, and distribution, between knowledge production and consumption, or among knowledge production, distribution, and consumption.

3. Building up an NIS system dynamics model

3.1 Building up an NIS causal loop diagram to analyze the effects of OI policies on NISs

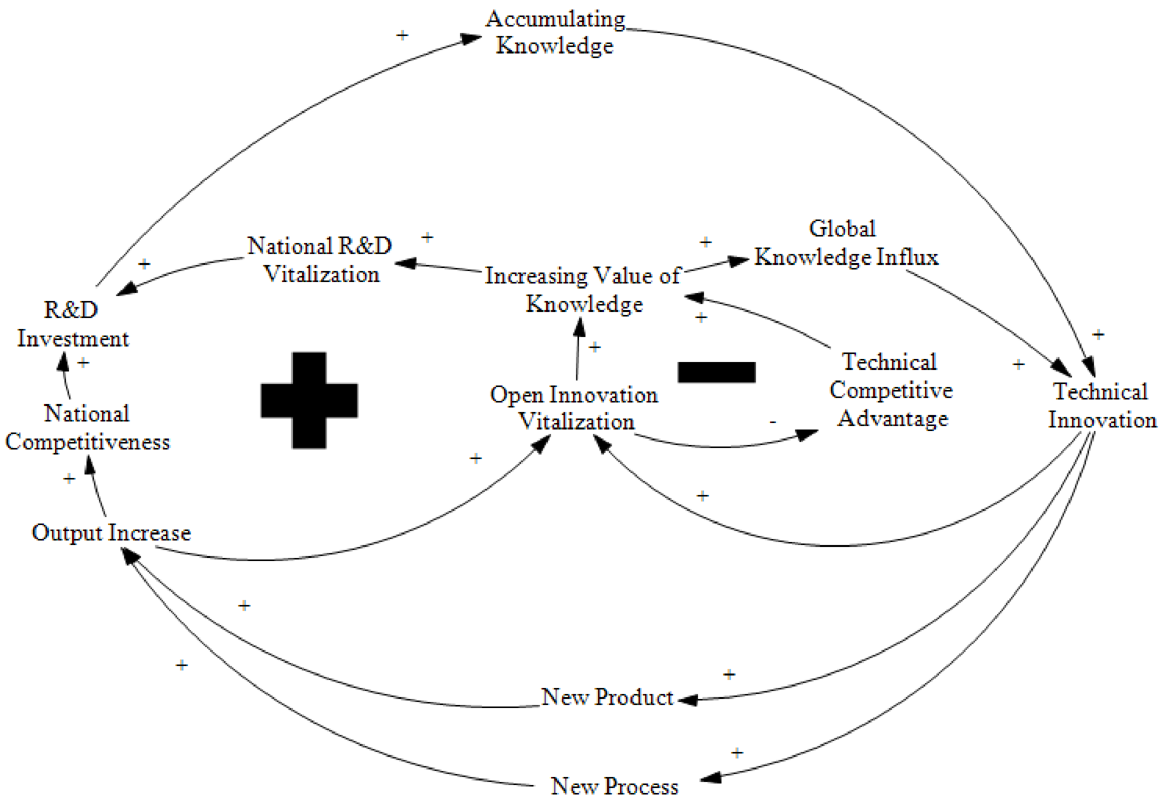

Fig. 1. NIS causal loop to analyze the effects of OI policy on NIS.

Based on almost all NIS studies shown in Table 2, an NIS causal loop diagram was established according to the frame of cumulative causation between technology and growth as seen in Fig. 1. This was prepared on the basis of the conceptual and logical positive feedback loop of NISs, that is, systematic links that connect knowledge accumulation and activation of inflows of global knowledge as well as increases in technical innovation. In addition, enhancement of product and process innovation is connected with improvement of national competitiveness through output increase. In the end, increases in new research and development investments trigger a new loop.

As shown in Table 3, policies for promoting open innovation aim at enhancing the value of knowledge first. The enhanced value of knowledge promotes research and development investments in the country and inflows of knowledge and technology from foreign countries in diverse forms and through diverse channels. In the stage of intervention by OI policies for activating OI, increases in the value of knowledge are triggered by the activation of OI, and the effects of such increases on domestic and foreign elements are explicitly reflected in the NIS causal loop diagram.

Also, dissipation of the price advantage or differentiation advantage by the enterprises that own technologies at the enterprise level is indicated as a negative feedback loop [31]. Although OI promotes knowledge production and distribution and brings about the enhancement of national competitiveness at the NIS level, the activation of OI in relation to certain technologies dissipates the competitive advantage of the relevant companies [17]. Thus, the effects of OI policies on NISs can be simulated more practically by including the negative feedback loop of OI.

The relation among individual variables constituting a causal loop has been sufficiently elucidated already by many previous studies, as shown in Table 4. However, this study shows the systematic and creative composition of the causal relationships among related variables as a causal loop diagram.

Table 4
Grounds for setting the relationships between variables in the causal loop.

Relationships between variables	References
Open innovation vitalization →+ increasing value of knowledge	Chesbrough et al. [8] Jong et al. [20] Wang et al. [45]
Open innovation vitalization →- technological competitive advantage	Porter [31] Fuller and Stopford [17]
Increasing value of knowledge →+ national R&D vitalization →+ R&D investment	Richardson [32] Sterman [41] Romer [34] Ford and Sterman [12]
Increasing value of knowledge →+ global knowledge influx →+ technical innovation	Castellacci and Natera [6] Wong [47] Niosi [27] Sterman[39]
R&D investment →+ accumulating knowledge →+ technical innovation →+ new product, new process →+ output increase →+ national competitiveness →+ R&D investment	Freeman [16] Lundvall [23] Nelson [49] OECD [29] Metcalfe and Ramlogan [26] Samara et al. [35] Kim and An [22] Won and Yun [46]

3.2 NIS system dynamics model building to analyze the effects of OI policy on NIS

This SD model is based on normalized unit modeling by elementary relationships (NUBMER). That is, this model converts predefined causal loop diagrams into system dynamics models while eliminating researchers' thoughts as far as possible. This method sets all the relationships between stock and flow variables, and equalizes the measurement units of these variables into values ranging from 0 to 1 [41]. However, grounds for setting the initial values of individual variables were obtained from the Global Competitiveness Index of the World Economic Forum, the UNESCO Science Report 2010, and the World Bank database to set the stock variables to fit for reality. This will enhance the reality and effectiveness of the results of simulations of the effects of open innovation policies on the Cambodian NIS.

Stock variables have decreasing aspects in Fig. 2 to reflect the effects of the negative feedback loop made by the decreases in technological competitiveness advantages that might be caused by open innovation at the enterprise level.

In the NIS SD model, eight stock variables were defined, as shown in Table 4. All other variables are flow variables. Model formulas for the variables were basically composed in accordance with the NUBMER, and their concrete contents are shown in Appendix 1.

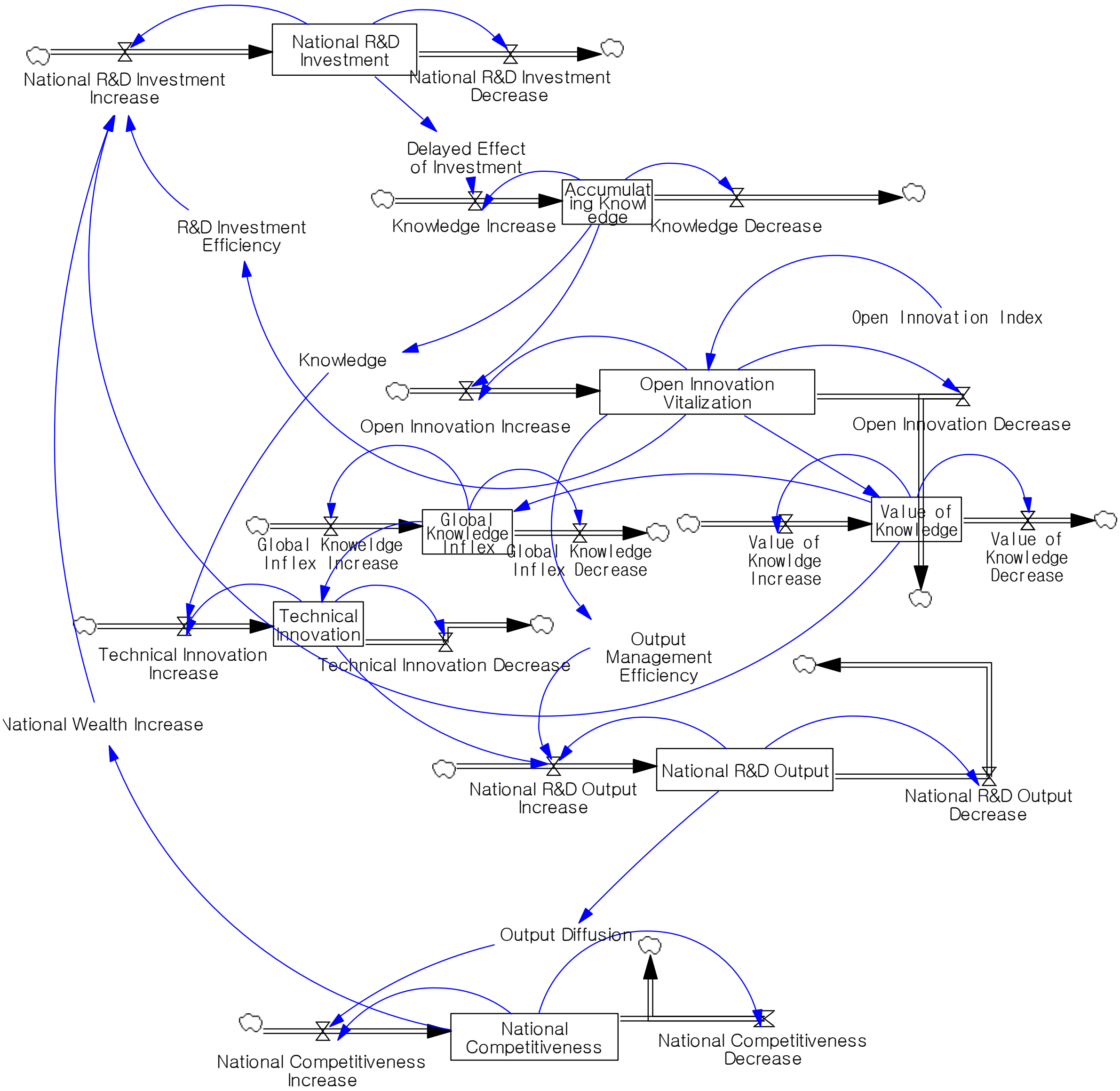

Fig. 2. NIS system dynamics model to simulate the effects of OI policy on NIS.

Table 5
Stock variables of the NIS SD model.

Variables	Explaining the Variables
Accumulating knowledge	Increases in protected and protectable knowledge in the country Ground for the initial value = 0.1: Knowledge economy index 137th among 145 based on World Bank database, accessed March 2010 [44].
Global knowledge influx	Influxes of protected and protectable knowledge from foreign countries Ground for the initial value = 0.3: Availability of latest technologies 103rd and FDI and technology transfer 38th, although FDI-based technology transfers are being activated, these technology transfers have a limitation that the technologies are not newest technologies but are mainly technologies at their early stages of development [48].
National competitiveness	Overall competition ability of the country reviewed from the viewpoint of relative comparison with foreign countries Ground for the initial value = 0.1: Global competitiveness index

	2010–2011, placed 109th among 139 countries, and Cambodia belongs to factor-driven economies [48]
"National R&D Investment"	Research and development investments in the entire country = government research and development investments + private research and development investments Ground for the initial value = 0.1: R&D investment = 0.05% of GDP, and researchers per million population = 17 (compared to Vietnam: 0.19% and 115) [44].
"National R&D Output"	Outcomes made by research and development investments in the entire country Ground for the initial value = 0.1: The number of SCI papers during 1998–2008 was 396 (compared to that in Singapore (45,943) and in the Philippines (4,079) in the same period), and the numbers of USPTO registered patents were one in 2004, one in 2006, and zero in 2007 (1382cases Australia in 2007, 212 cases Malaysia in 2007) [44].
Open innovation vitalization	The degree of activation of OI at the country level The values of the open innovation index are estimated based on the level of OI policies as 0.1, 0.5, and 0.8 when OI policies are weak, considerable, and generally very strong, respectively
Technical innovation	Cases where protected or protectable knowledge is concretely applied to enterprises, thus, technological innovation occurs Ground for the initial value = 0.1: capacity for innovation 101st among 139 countries [48]
Value of knowledge	Economic value of protected or protectable knowledge produced or distributed in the country Ground for the initial value = 0.1: Utility patents per million population 90th [48], and GDP per capita $2,200 and 187th in 2011, according to the World Bank database

4. Simulation

4.1 The structure of simulation

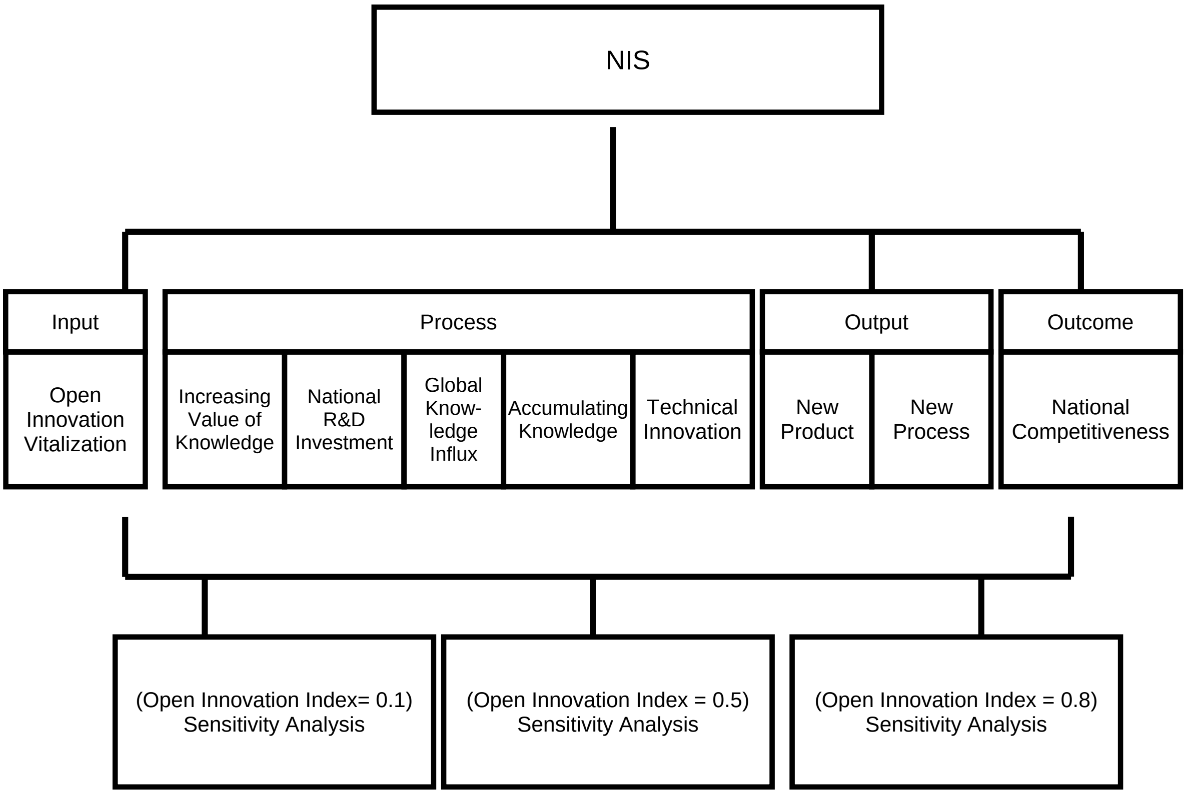

Fig. 3. Simulation structure.

In this work, simulation studies were conducted in the structure shown in Fig. 3. That is, stock variables of OI vitalization were presumed to be input variables indicating the degree to which the government intervenes in open innovation with policies. Note that attention should be paid to the characteristics of OI policies. Basically, OI policies are not limited to the production of knowledge and technology but cover knowledge distribution and consumption as well. In industrial society of the CI paradigm, most government policies focus on the production of knowledge and technology. This corresponds to low-level OI. However, as a knowledge-based economy is established, knowledge distribution and consumption have important values. OI policies include knowledge distribution and consumption as essential subjects of policies with knowledge production [8, 20, 45].

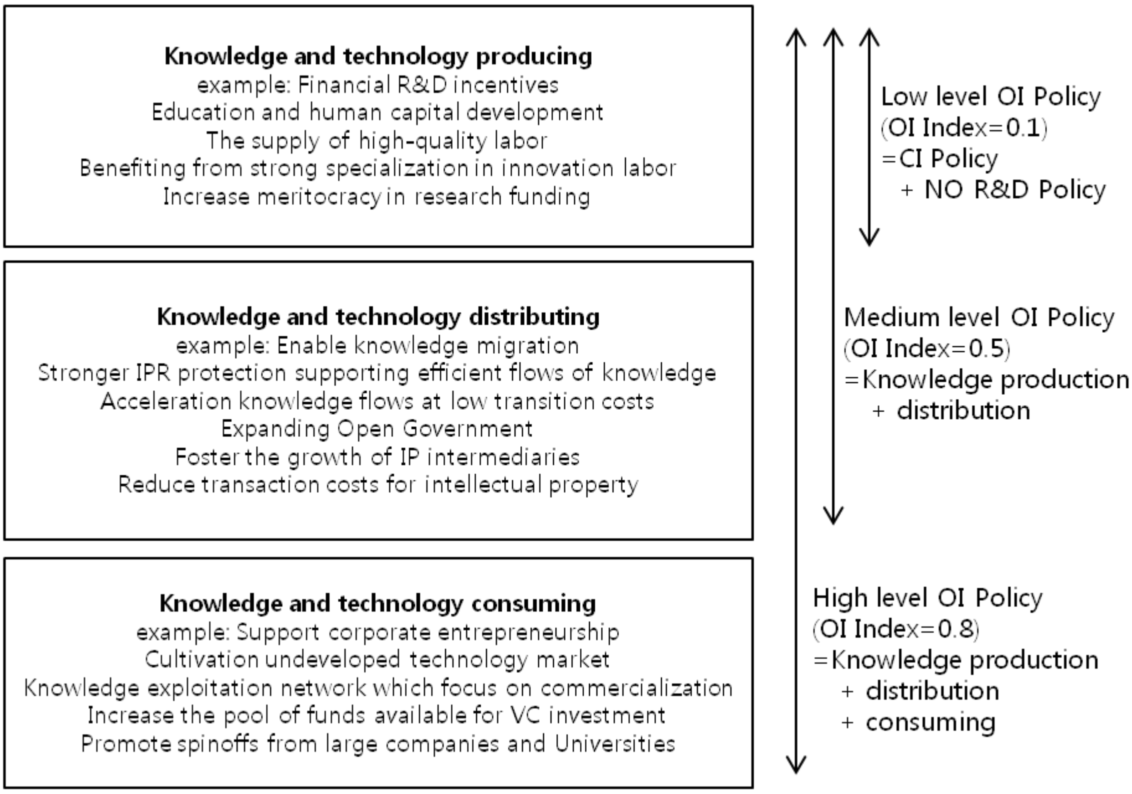

Fig. 4. OI policy as knowledge production, distribution, and consumption.

In this study, as shown in Fig. 4, OI polices were divided into low-level OI policies, medium-level OI policies that cover knowledge production and distribution, and high-level OI policies that cover knowledge production, distribution, and consumption. The OI indexes of these policies were set as 0.1, 0.5, and 0.8 to simulate the results.

The level at which a government's OI policies are not properly exercised and enterprises' OI practices in the market are insignificant was assigned the open innovation index of 0.1. The level at which the government's OI policies are partially exercised, that is, concentrated mainly on the production and distribution of knowledge and technology using some of diverse measures of OI policies and OI practices in the market are activated moderately was assigned the open innovation index of 0.5. The final level at which the government's OI policies are fully exercised, that is, exercised using diverse OI policy measures in all the areas of the production, distribution, and consumption of knowledge and technology and OI practices in the market are activated was assigned the open innovation index of 0.8.

4.2 Simulation results

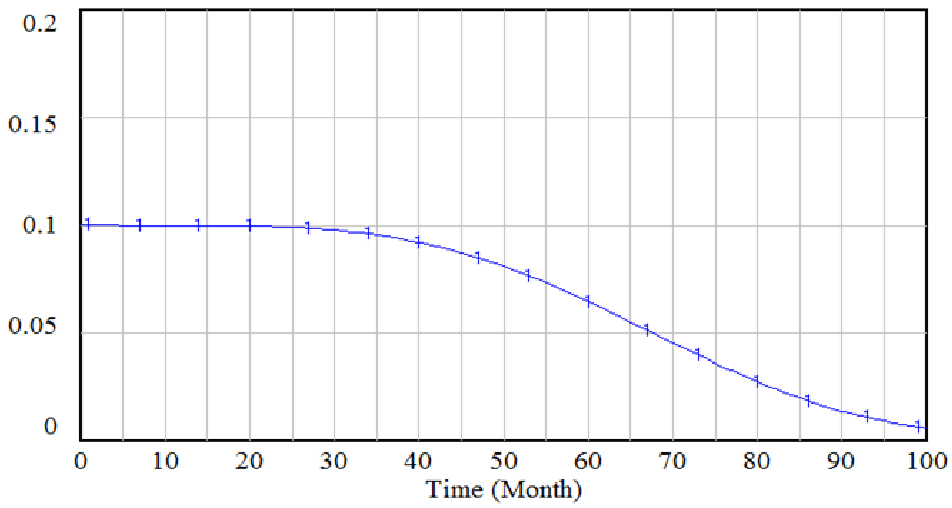

Fig. 5. The result of open innovation index = 0.1.

When there are few government OI policies, the national competitiveness in the NIS remains almost stagnant, as shown in Fig. 5. The stagnation inevitably precipitates declines in national competitiveness after a certain period of time. These simulation results show that in a knowledge-based economy, the government's OI policies are necessary to activate national innovation systems and improve national competitiveness. CI policies or government policies centered on knowledge production not including knowledge distribution or consumption reduce the possibility of faster distribution and use of knowledge and technologies existing in the world so that national competitiveness is not improved. Of course, the lack of government policies for the development of knowledge and technologies also leads to the lack of knowledge distribution and consumption as well as the lack of knowledge production, resulting in persistent stagnation of national competitiveness.

Fig. 6 indicates that when a country's open innovation policies are limited to the production and distribution of knowledge and technology, weak improvement of national competitiveness in the NIS occurs at a low level and disappears quickly. To continuously promote knowledge production, distribution, and consumption in the NIS and lead to permanent improvement of national competitiveness, partial open innovation policies are not enough. In the current knowledge-based economy, it is impossible to continuously maintain the national competitiveness of a country with only partial policies, such as increasing research and development investments in the country, intensive cultivation of excellent scientific technological manpower, and enhancing the fluidity of domestic and foreign knowledge and researchers. These simulation results show this reality intuitively.

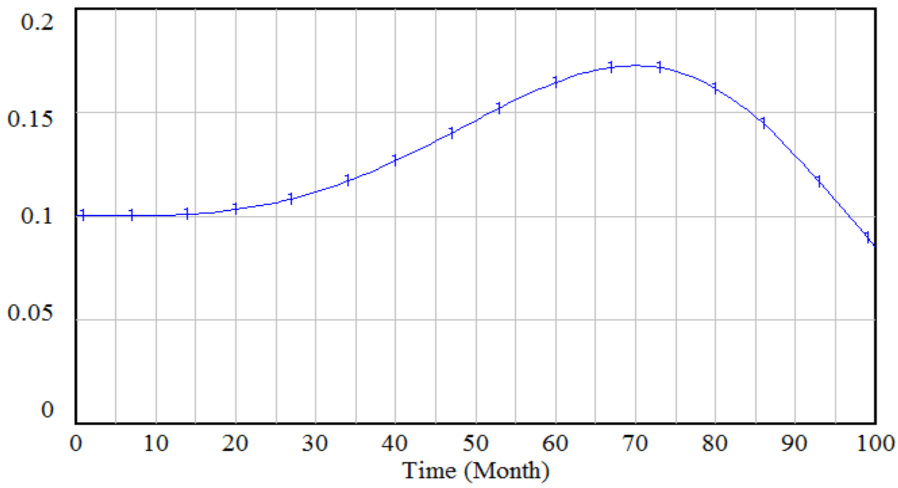

Fig. 6. The result of open innovation index = 0.5.

Fig. 7 intuitively shows the effects of a certain country's OI policies when the policies are not limited to the conventional expansion of research, and development investments in the country are multilateral covering all cycles of the production, distribution, and consumption of knowledge and technology. Policies such as actively introducing of diverse knowledge and technologies from foreign countries through various channels, improving the fluidity of domestic knowledge and technologies, enhancing entrepreneurship, and activating technology intermediary markets would be implemented. This figure shows that although the effects of these policies do not appear to be significant in the short-term, their effects in the mid-/long-term do not stop in a short time but lead to continuous improvement of national competitiveness.

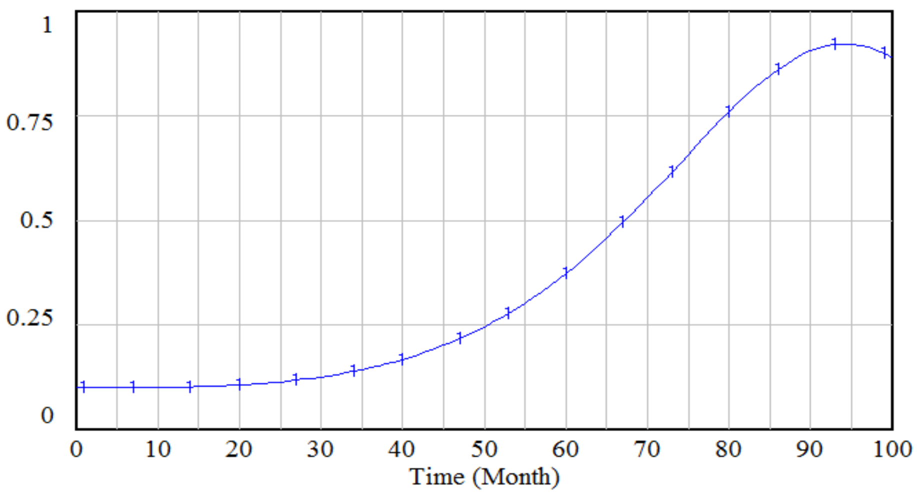

Fig. 7. The result of open innovation index = 0.8.

5. Applying to Cambodia NIS

5.1 Present state of the Cambodian NIS

Cambodia is still recovering from the trauma of the world and civil wars that decimated the country's scientific capacity in the 1970s [44]. Up to the present, Cambodia's private sector remains weak and very much dependent on both foreign direct investment (FDI) and official development assistance (ODA). Even though the Cambodian public sector shoulders most of the burden for national investment in knowledge-based development, including R&D, there is currently no concrete Cambodia national strategy for S&T, and Cambodian S&T policy remains fragmented and dispersed across the various ministries responsible for social and economic management and development [44].

The Cambodian national innovation system was set forth centering on the simulated structure of OI composed in this study, as shown in Table 6. In Cambodia, national research and development budgets have not been separately set thus far. Throughout the country, institutions, infrastructures, and macroeconomic environments have not been arranged; there is also no national-level integrated scientific technology policy. That is, the level of OI policies is very low; thus, the OI policy index is close to 0.1. Interviews with professors of Cambodia Norton University and other universities, indicated that the government invests very little in science and technology in the country; thus, the production of papers or patents is difficult. Furthermore, even representative large enterprises in Cambodia, namely, the Mong Reththy Group, cannot secure technologies and engineers necessary in the process of running agriculture, livestock industry, and basic manufacturing business; therefore, they obtain technologies and engineers from neighboring countries, such as Vietnam and Thailand. In addition, according to interviews with related persons of the Korea Trade-Investment Promotion Agency (KOTRA), even foreign enterprises planning to make large investments in manufacturing businesses in Cambodia cannot make investments promptly because not only basic technologies and engineers are insufficient but there is also no policy or investments by the Cambodian government; as a result foreigners' direct investments in the area of technology-intensive industries are not promptly activated. Researchers of the agricultural test division of Cambodia indicated that technologies and engineers were not sufficiently secured even in agriculture, which is one of the strongest industries in Cambodia. Thus, national research institutes and agriculture-related enterprises are in difficulty. Consequently, in Cambodia, at the national level, general policies or activities for knowledge production, distribution, and consumption are insufficient and, in particular, considerable limitations are seen in knowledge production.

This low level of Cambodian OI policies and the weak economic situation are creating very low records in higher education and training, technological readiness, researchers, technicians, R&D investment, knowledge economy index, scientific articles, patents, and high-tech exports in particular, as shown in Table 6.

Table 6
Situation of the Cambodian national innovation system.

Division	Situation	References
Input	Basic Requirements: 113th place - institution 94th place - infrastructure 114th place - macroeconomic environment 116th place, etc.	World Economic Forum [48]
	There is currently no overt national strategy for S&T.	UNESCO [44]
Process	Higher education and training: 122nd place	World Economic Forum [48]
	Technological readiness: 115th place	World Economic Forum [48]
	Number of researchers per million population (FTE): 17 (compared to Australia 4231, Vietnam 115)	UNESCO [44]
	Number of technicians per million population: 13 (compared to Australia 993, Malaysia 44)	UNESCO [44]
	R&D investment as % of GDP: 0.05 (compared to Australia 2.06, Vietnam 0.19)	UNESCO [44]
	Knowledge Economy Index ranking of 145 countries: 137th place (compared to Australia 11th place, Vietnam 106th place)	UNESCO [44] World Bank database [51], accessed March 2010
	Number of English-language scientific articles by authors from Southeast Asia and Oceania, 1998–2008: 401 (compared to Australia: 238,076 and Vietnam: 5070)	UNESCO [44] Thomson Reuters' (Scientific) Inc. Web of

		Science [52]
	Number of USPTO registered patents 2004: 1 / 2007: 0 (compared to Australia 2004: 1068 / 2007: 1382 and Vietnam: 2004: 2 / 2007: 1)	UNESCO [44]
	High-tech exports (2008): 2,797.5 US$ millions (compared to Australia: 187,039 US$ millions and Vietnam: 48,561.3 US$ millions	UNESCO [44] United Nations Trade database [53]
Output	Innovation 108th place	World Economic Forum [48]
Outcome	National competitiveness 109th place	World Economic Forum [48]

Source: General summary from the World Economic Forum [48], UNESCO [44]

Eventually, the Cambodian national innovation system showed 108th in innovation level and 109th in national competitiveness level.

5.2 Design of high-level OI policies for enhancing Cambodian national competitiveness

The simulation results of the effects of OI policies on NISs indicated that policies that promote production, distribution, and consumption of knowledge could continuously improve national competitiveness in the long run. The reality of the Cambodian NIS is that even closed innovation policies for sufficient knowledge production have not been properly activated. Comparing the simulation results and the reality of the Cambodian NIS, it is clear that, to continuously improve Cambodian national competitiveness, full OI policies that can promote knowledge production, distribution, and consumption together are essential.

Table 7
Design of open innovation policies for continuous improvement of Cambodian national competitiveness.

Target Function	Open Innovation Policy Contents
Knowledge and technology creation	- Organization and operation of national research and development programs: (tentative name) The Cambodia 2020 research and development program will be organized to increase national research and development investments beginning from 0.05% of the national budget to 1% of the national budget by 2020 - All departments will establish systems for the investigation, analysis, and evaluation of national research and development projects - National scientific technology investment plans will be established - Scientific technology manpower development plans will be established - An administrative organization dedicated to national scientific technologies and a national scientific technology deliberative committee will be organized
Knowledge and technology distribution	- Plans to promote cooperative research and development by the industrial world, academia, and research institutes will be established - International scientific technological cooperation plans will be established: national-level international scientific technological cooperation networks will be established - Overseas posting of programs to foster scientific technologies in all areas of Cambodia will be established: through the (tentative name) Cambodian scientific technology global Columbus program, cooperation with advanced countries for the development of human resources with scientific technologies will be promoted

	- Programs for free patent transfers from foreign countries will be established - Participations in international joint research and development programs will be activated - Scientific technology and information distribution plans will be established: national scientific technology databases and management systems will be developed and operated - Through the organization and operation of the (tentative name) open Cambodian scientific technology information center, the distribution of scientific technology and information will be promoted not only in Cambodia but also at the global level
Knowledge and technology consumption	- Establishment of ICT action plans: To activate new ICT technology and knowledge-based enterprises and industries through the activation of the production and distribution of knowledge and technology in the area of ICT, diverse comprehensive plans will be established and implemented - Establishment of agricultural development action plans: comprehensive plans intended to promote the production, distribution, and consumption of knowledge and technologies in the area of agriculture, which is one of the largest industries in Cambodia, will be established and implemented - Establishment of basic industry action plans: Concrete plans to promote the production, distribution, and consumption of technologies in the area of basic industries in Cambodia will be established and implemented - Through the (tentative name) Cambodian scientific technology center program, excellent scientific technological talents and scientific technological knowledge will be continuously produced, and the processes will be operated through the joint participation of the industrial world, academia, and research institutes. - Through the planning of the (tentative name) Cambodian scientific technology policy and management graduate school program, technology transfers and the deepening and development of technical business foundation oriented technology policies and management will be promoted at the level of the Cambodian government and in the private sector

This research team's plan sets a target for the long-term and continuous effects of open innovation policies on the NIS to improve national competitiveness. Accordingly, as shown in Table 7, the creation, distribution, and consumption of knowledge and technology were set as concrete contents of the policies. Knowledge and technology creation policies encompass the establishment of national research and development programs, national S&T investment plans, and national scientific technological manpower development plans, as well as the organization of a national administrative organization dedicated to S&T and the national scientific technology deliberative committee.

However, knowledge and technology distribution policies consist of the establishment of industry-academy collaborative research and development promotion plans, the establishment of international S&T cooperation systems, overseas dispatching programs for fostering Cambodian S&T, the establishment of programs for free patent transfers from foreign countries, and the establishment of S&T information distribution promotion systems. Although even the production of knowledge and technologies has not been activated in Cambodia at the moment, the Cambodian S&T master plan includes not only the production of S&T and knowledge but also the promotion of their distribution.

In addition, the establishment of ICT, agriculture, and a primary industry action plan, and Cambodia science technology research center program are included in the Cambodian S&T master plan. These are the results of the establishment of the Cambodian S&T master plan from the active viewpoint of open innovation policies that considers the production and distribution of knowledge and technologies as well as their consumption.

That is, the Cambodian S&T master plan is intended to promote the production, distribution, and consumption of knowledge and technologies. It is aimed at continuous improvement of Cambodian national competitiveness in the long run, as seen in the results of simulations of the system dynamics regarding the effects of high-level open innovation policies on the NIS.

6. Conclusion

6.1 Summary

This research paper obtained answers to the following research problem: How do open innovation policies affect NISs? To this end, the characteristics of open innovation policies were elucidated through literature review. Open innovation policies are characterized by their simultaneous promotion of the creation, distribution, and consumption of knowledge and technologies.

Next, previous studies of NISs, open innovation policies, and related system dynamics were analyzed to establish an NIS causal loop diagram and a system dynamics system to analyze the effects of OI policies on NISs. The effects of OI policies on national competitiveness were simulated for OI policies with various intensities. These simulations indicated that whereas moderate open innovation policies had slight effects to improve national competitiveness and the effects did not persist, high-level open innovation policies clearly had significant and persisting effects, although the effects appeared in the long run.

Based on the results of the simulations of the effects of open innovation policies, the Cambodian S&T master plan was established with concrete contents of science technology policies intended to promote the production, distribution, and consumption of technologies and knowledge in Cambodia.

6.2 Implication

This study is meaningful in that it simulated the effects of open innovation policies on NISs in modern society. Recently, studies of open innovation policies have been activated while being conceptually established. This study expanded the research on open innovation policy in that it estimated the effects by simulations through an NIS causal loop diagram and system dynamics.

This study also established the characteristics of open innovation policies differentiated from existing science technology policies or research and development policies through the review of previous studies of open innovation policies and NISs. That is, this study clearly established that open innovation policies aim at the production as well as the distribution and consumption of knowledge and technologies through the results of analysis of previous studies. Furthermore, this study elucidated differences in the effects the open innovation policies on NISs using simulations according to the degree of integrated implementation of the production, distribution, and consumption of knowledge and technologies. The simulations showed that, although middle-level open innovation policies might bring about low-level effects to improve national competitiveness in the short-term, they could not create long-term, continuous effects. These results have been historically proved in cases of communist countries, such East Germany, and other countries of eastern Europe and the former Soviet Union. The fact that high-level open innovation policies become drivers of long-term and continuous growth of NIS has been proved in Israel, northern European countries, the Silicon Valley region in the USA, and the Zhongguancun region in China.

Finally, this study is also meaningful in that it not only conducted simulations but also applied the simulation models to the Cambodian NIS to develop concrete contents of policies in the Cambodian S&T master plan. This study also elucidated the reason why Cambodian national competitiveness has remained low in terms of the effects of open innovation policies on NISs; it applied the simulation results to the development of policy contents to promote the production, distribution, and consumption of knowledge rather than policies to just increase the production of knowledge and technologies in the country.

6.3 Subsequent research topic

Follow-up studies are still required to elaborate the NIS system dynamics and the causal loop diagram elucidated in this study for individual open innovation policies and implement negative feedback loops for those in system dynamics. That is, studies to develop causal loop diagrams and analyze NISs for the simulations of specific open innovation policies are necessary.

In addition, to elucidate the effects of open innovation strategies of individual enterprises on corporate performance, corporate-level open innovation casual loop diagrams and the relevant system dynamics should be developed. That is, studies to develop system dynamics are necessary for the simulation of effects of open innovation strategies at the company level.

Appendix 1. Numeric Formula for Modeling

(01) Accumulating Knowledge= INTEG (+Knowledge Increase-Knowledge Decrease, 0.1)
- 0.1 : initial value

(02) Delayed Effect of Investment= DELAY1 ("National R&D Investment", 12)
- 12: modulated coefficient

(03) Global Knowledge Influx Increase= Global Knowledge Influx * 0.3
- 0.3: modulated coefficient

(04) Global Knowledge Influx= INTEG ((Global Knoweldge Influx Increase - Global Knowledge Influx Decrease) * Value of Knowledge , 0.1)
- 0.1 : initial value

(05) Global Knowledge Influx Decrease=Global Knowledge Influx * 0.02
- 0.02: modulated coefficient

(06) Knowledge = SMOOTH (Accumulating Knowledge , 12)
- 12: modulated coefficient

(07) Knowledge Decrease= Accumulating Knowledge*0.2
- 0.2: modulated coefficient

(08) Knowledge Increase= Delayed Effect of Investment* 0.8* Accumulating Knowledge
- 0.8: modulated coefficient

(09) National Competitiveness= INTEG ((National Competitiveness Increase-National Competitiveness Decrease)*8, 0.1)
- 0.1 : initial value
- 8 : modulated coefficient

(10) National Competitiveness Decrease= National Competitiveness*0.1
- 0.1 : initial value

(11) National Competitiveness Increase= Output Diffusion*National Competitiveness

(12) "National R&D Investment Decrease"= "National R&D Investment"*0.01
- 0.01: modulated coefficient

(13) "National R&D Investment Increase"=(National Wealth Increase + "R&D Investment Efficiency") * 0.1 * "National R&D Investment"
* 0.5 * Value of Knowledge

- 0.1, 0.5: modulated coefficient

(14) "National R&D Investment"= INTEG ("National R&D Investment Increase"-"National R&D Investment Decrease", 0.1)
- 0.1 : initial value

(15) "National R&D Output Decrease"= "National R&D Output"*0.01
- 0.01: modulated coefficient

(16) "National R&D Output Increase"= (Technical Innovation+Output Management Efficiency)*0.1*"National R&D Output"*0.5
- 0.1, 0.5: modulated coefficient

(17) "National R&D Output"= INTEG (+"National R&D Output Increase"-"National R&D Output Decrease",0.1)
- 0.1 : initial value

(18) National Wealth Increase= SMOOTH (National Competitiveness, 12)
- 12: modulated coefficient

(19) Open Innovation Decrease=Open Innovation Vitalization*0.01
- 0.01: modulated coefficient

(20) Open Innovation Increase=Accumulating Knowledge* Open Innovation Vitalization

(21) Open Innovation Vitalization= INTEG ((+Open Innovation Increase-Open Innovation Decrease)*Open Innovation Index, 0.1)
- 0.1 : initial value

(22) Output Diffusion=SMOOTH ("National R&D Output", 12)
- 12: modulated coefficient

(23) Output Management Efficiency=Open Innovation Vitalization

(24) "R&D Investment Efficiency"=SMOOTH (Open Innovation Vitalization, 12)
- 12: modulated coefficient

(25) Technical Innovation= INTEG (Technical Innovation Increase*Global Knowledge Influx -Technical Innovation Decrease,0.1)
- 0.1 : initial value

(26) Technical Innovation Decrease=Technical Innovation*0.01
- 0.01: modulated coefficient

(27) Technical Innovation Increase=Knowledge*0.1* Technical Innovation
- 0.1: modulated coefficient

(28) Value of Knowledge Increase=Value of Knowledge * 0.1
- 0.1: modulated coefficient

(29) Value of Knowledge= INTEG ((Value of Knowledge Increase-Value of Knowledge Decrease) * Open Innovation Vitalization, 0.1)
- 0.1 : initial value

(30) Value of Knowledge Decrease= Value of Knowledge * 0.1
- 0.1: modulated coefficient

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