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Intellectual Property Management in Publicly Funded R&D Program and Projects: Optimizing Principal-Agent Relationship through Transdisciplinary Approach

Shuto Miyashita [1,2], Shogo Katoh [1,2], Tomohiro Anzai [2] and Shintaro Sengoku [1,2,*]

1 Department of Innovation Science, School of Environment and Society, Tokyo Institute of Technology, Tokyo 152-8550, Japan; miyashita.s.ae@m.titech.ac.jp (S.M.); katoh.s.ab@m.titech.ac.jp (S.K.)

2 Kawasaki Institute of Industrial Promotion, Kawasaki, Kanagawa 212-0013, Japan; anzai-tr@umin.ac.jp

* Correspondence: sengoku.s.aa@m.titech.ac.jp; Tel.: +81-3-3454-8907

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Abstract: Large-scale, publicly funded research and development (R&D) programs are implemented to accelerate state-of-the-art science, technology, and innovation applications that are expected to solve various societal problems. The present study aims to build on the body of theory on the mechanisms that promote or impede the creation of intellectual property in such programs. Using a mixed methods approach and combining quantitative network analysis and qualitative semistructured interviews, we conducted a case study to investigate best practices in terms of intellectual property creation in a Japanese governmental research and development program. The results of the network analysis showed that the core/periphery structure in the co-inventor network of patents and joint application by a university and a startup promoted intellectual property creation. The results of the interview confirmed the significance of a reciprocal mindset, which the researchers in academia could acquire through collaboration with a startup. These results suggest that a knowledge logistics system for agile intellectual property management can be established by learning to acquire tacit knowledge on social implementation. Furthermore, we focus on the principal–agent relationship between knowledge producers and knowledge consumers as a factor that impedes the creation of intellectual property. We also discuss adverse selection and moral hazards caused by information asymmetry between knowledge producers and knowledge consumers and how to deal with them.

Keywords: intellectual property; startup; knowledge logistics information asymmetry; adverse selection; moral hazard; mixed methods

1. Introduction

The promotion of innovation based on state-of-the-art science and technology is a driving force for economic growth and industrial development, as well as a powerful tool for solving the various societal challenges facing our world. In addition, the significance and benefits of innovation have recently been emphasized in sustainable development goals (SDGs) [1,2]. In particular, the promotion of open innovation [3] based on cooperation amongst academia, industry, and government—so-called university–industry–government collaboration—is a key agenda in science, technology, and innovation policy, and governmental research and development (R&D) programs are continuously being implemented [4,5]. At the same time, the increasing size and complexity of R&D projects pose a managerial issue [6–9]. Specifically, the construction of a management system to promote smooth cooperation among actors with different specialties and sectors is a serious issue in R&D management [10–12].

In innovation-oriented R&D projects, the strategic creation of intellectual property, especially patent management, has been emphasized in recent years [13,14]. Such projects not only call for the publication of research results (which many scientists prefer), but also the simultaneous pursuit of patents. The pursuit of both patents and publications must be strategic, as patent applications must be filed prior to the publication of related papers [15]. The creation of intellectual property is essential for sustainable science, technology, and innovation; transforming R&D outcomes into transferable goods such as patents promotes knowledge dissemination and further innovation in society [16]. In fact, it has been pointed out that intellectual property can influence a wide range of SDGs and contribute to solving many societal issues, such as food, health, energy, and climate change [17,18]. Bridging the technologies created by universities and public research institutions for industry is an essential part of sustainable development as a cue to solve complex problems in society [14,19,20]. In other words, the creation of intellectual property is based on reciprocal relationships among different sectors and requires strategic and organizational management.

Although the creation of intellectual property is strongly encouraged in publicly funded R&D programs, making the R&D outcomes fruitful in terms of industrialization and commercialization is still a challenging problem. Specifically, in the case of state-of-the-art R&D, there is information asymmetry and mismatch in the sense of purpose between knowledge producers (i.e., academia) and knowledge consumers (i.e., practitioners). To elaborate further, a knowledge logistics system [21,22] that can autonomously and continuously supply high-quality knowledge to knowledge consumers must be established.

The present study aims to develop a comprehensible theory on the mechanisms that promote or impede the creation of intellectual property, and then to develop and propose a mode of program and project management for stat-of-the-art technologies. This study focuses on a large-scale R&D project that is based on university–industry–government collaboration, and carries out a case study using the mixed methods approach [23,24]. An exploratory study was conducted to investigate the factors that promote or impede the creation of intellectual property by using a combination of quantitative analysis based on a mixed approach with co-inventor networks built from patent data and qualitative observation.

2. Research Design

2.1. Theoretical Background

The SDGs of the 2030 Agenda for sustainable development were adopted by the United Nations Summit in 2015 [25], aiming to achieve a sustainable and better world by reaching the Millennium Development Goals (MDGs) set in 2001. It consists of 17 goals, 169 targets and 247 indicators, which shows that each goal is based on a complex of various social and environmental problems [26]. Among the 17 goals, for example, Goal 3 (“Ensure healthy lives and promote well-being for all at all ages”) and Goal 9 (“Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation”) are notable themes for the ecosystem and human well-being [27], where the contribution of state-of-the-art science and technology was clearly identified as a means by which to achieve sustainable societies around the world [28,29].

In this context, open innovation is essential for academia-centered publicly funded R&D projects that are being implemented to address common global challenges. Open innovation theory emphasizes the role of knowledge access and networks in promoting innovation [3,30–32]; in scientific research, these roles are also discussed in the context of university–industry–government collaboration [4,14,33]. It is possible to achieve sustainable goals beyond the mere pursuit of economic growth through the collaboration of diverse stakeholders. In a field strongly driven by science and technology, innovators must properly manage their intellectual property to benefit from innovation [13,14].

Another specific problem, especially in academia, is the fragmentation of individual academic disciplines [34]. On the other hand, knowledge of a particular discipline alone cannot comprehensively deal with the complex problems that society faces [34]. Therefore, an interdisciplinary approach that integrates knowledge from various academic disciplines is necessary [35]. Including the discussion in the previous paragraph, a transdisciplinary approach—that includes interdisciplinary knowledge integration and the involvement of professional and social stakeholders outside of academia—is needed to solve the huge and complex challenges addressed by the SDGs [36,37].

Transdisciplinary research is currently an inclusive concept to achieve the SDGs through multisectorial interactions [38–40] while optimizing the intricate coordination and conflicts among stakeholders. In such transdisciplinary research, since stakeholders with various interests are usually involved, the principal–agent relationship [41–43] can be a cue to mitigate conflicts of interest which can cause undesirable agent behaviors, such as adverse selection and moral hazard, for the principals because of information asymmetry [44–48]. These problems can inhibit the efficient creation of outcomes and, furthermore, incur additional costs to prevent them.

Adverse selection [45] is a phenomenon in which the inherently desirable option for the principal is rejected due to the information asymmetry before transactions. In general, there are two types of methods to prevent adverse selection: screening and signaling [49–51]. Screening means that the principals obtain information about the agent type by presenting them with multiple choices and making them choose. Signaling involves identifying information asymmetry disclosing the agent type to the principals.

On the other hand, moral hazard is a phenomenon in which the expected performance is undermined by the agent's opportunistic behavior because the principals are unaware of such behavior. The means of preventing moral hazard include monitoring and incentive contracts [52–54]. Monitoring is a means of inhibiting opportunistic behavior on the part of the agent by having the principal observe the agent's performance. Incentive contracts are a way for the agent to select the desirable behavior for the principal by aligning the interests of the two parties.

2.2. The Case

As the focus of our case study, we selected the governmental R&D support initiative that was implemented in Japan over a five-year period from 2009 to 2013: the Funding Program for World-Leading Innovative R&D on Science and Technology (FIRST Program) [55], which provided considerable R&D funds for projects organized by Japan's top 30 researchers, selected for sustainable growth in international industrial competitiveness by promoting world-class advanced R&D; and Development of Innovative Diagnostic and Therapeutic Systems Based on Nanobiotechnology, known as NanoBio First [56], which is one of the projects funded by the FIRST Program to conduct R&D of technologies for the diagnosis and treatment of intractable diseases such as cancer through the use of nanobiotechnology.

In milestone evaluations of the FIRST Program, several issues related to intellectual property were identified. First, the interim evaluation [57] pointed out that patent applications had been sluggish in many projects. Although ex post evaluation at the end of the program [58] reported an improvement in this regard (Figure 1), the number of registrations for patent applications, especially international patents, tended to be low, and showed notably differences among projects, even though support system for intellectual property creation was implemented in the FIRST Program. This might have been due to a time lag, because the follow-up evaluations [59] reported that the number of patent applications, registrations, and licenses had been increasing since the end of the FIRST program, and that the performance was relatively good compared to the total of Japanese universities.

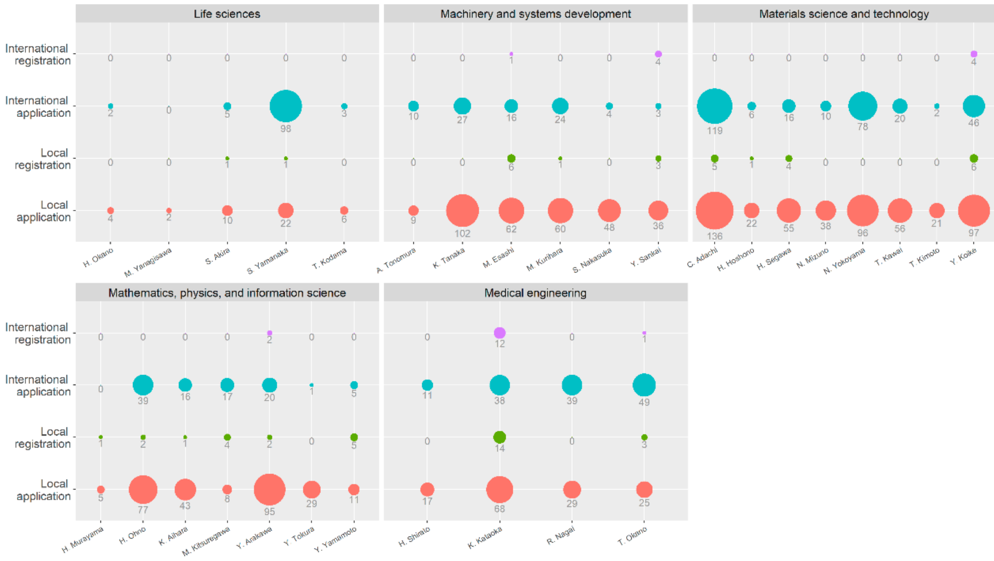

Figure 1. Bubble charts summarizing the number of local applications, local registrations, international applications, and international registrations of patents created during the FIRST Program; these are divided into five categories: Life sciences, Machinery and systems development, Materials science and technology, Mathematics, physics and information science, and Medical engineering.

However, even considering differences in the field of R&D, the establishment of a system enabling the conversion R&D outcomes into intellectual property, during or as quickly as possible after the completion of the project, is essential for the sustainable development of industrial competitiveness. Therefore, the goal of this study is to identify mechanisms that promote the creation intellectual property and theory building with a view to implementing a function of the overall R&D program from the best practices (i.e., NanoBio First).

3. Materials and Methods

To explore the factors that promote and impede the creation of intellectual property in a large-scale R&D project, a case study was conducted using a mixed-methods approach [24,60,61], a methodology that combines quantitative and qualitative analysis for a deeper understanding of complex phenomena. In this study, we observed the results of a network analysis using bibliographic data of patents (i.e., patentometric analysis), and conducted triangulation by qualitatively confirming their meaning through semistructured interviews with project leaders. This approach was based on similar previous studies [7,10]. This study follows the framework of exploratory sequential design in the sense that the results of its quantitative analysis are supported by a qualitative analysis [60,61]. The specific steps of the analysis are as follows.

1. Collection of patent data from NanoBio First
2. Network analysis based on co-inventor networks
3. Semistructured interviews with a project leader.

For data processing, such as the aggregation of patent data and the generation of an adjacency matrix for the co-inventor network, we used Python. We also used R and its package "igraph" to calculate the degree centrality and betweenness centrality of each inventor in the co-inventor network. In addition, we used Gephi to visualize the co-inventor network.

3.1. Collection of Patent Data

Initially, we obtained internal documents that described patent applications associated with NanoBio First during project period (2009–2013). On the basis of these documents, we compiled a list of patents created by NanoBio First and aggregated patent information by family [62]. We then downloaded PDF files of the patent documents from the Japan Platform for Patent Information (J-PlatPat) [63], a database of the National Center for Industrial Property Information and Training (INPIT) in Japan, and Espacenet, an online database of the European Patent Office [64]. Information on the inventors and their affiliations was extracted from the documents of each patent family and compiled for each family. Finally, 67 patent family-data were used as the dataset for the analysis.

3.2. Quantitative Analysis: Network Analysis Based on Co-inventor Network

Patent information is often used to quantitatively analyze technological trends and the impact of industrial R&D [64–67]. For example, the citation count of patents is used as a measure of the importance of a technology [68]. In this study, we adopted the perspective of so-called patentometrics [69,70], which is a methodology that applies scientometric or bibliometric approaches to patents, instead of academic publication. On the basis of the network that represents the collaborative relationship between inventors, we conducted a co-inventor analysis, corresponding to the coauthor analysis in scientometrics.

A co-inventor network is a network in which nodes represent inventors and the edges represent the interrelationships among co-inventors. In this analysis, a co-inventor network was constructed using the following procedure: (i) information about the inventors and their affiliations was extracted from the patent family data and a list of inventor information was generated; (ii) an adjacency matrix was generated by setting edges between inventors (i.e., nodes) for all combinations of co-inventors in each patent; (iii) after anonymizing for privacy protection, the adjacency matrix was transformed into a network object to add information about the affiliation of each node.

To identify the key actors in this co-inventor network, node centrality indices were computed. As in the previous study, the degree centrality and betweenness centrality of each node were calculated, and nodes with high centrality were extracted as key actors. On the basis of the structural features of the co-inventor network and the information on high centrality actors, we discussed the factors that promoted the creation of patents in NanoBio First.

3.3. Qualitative Analysis: Semistructured Interview with Project Leader

The second step of our analysis was a qualitative study aimed at enriching the results of the quantitative analysis with additional in-depth and contextualized insights into the actual understanding of NanoBio First and the factors that promote patent creation [23]. We conducted a 60-min, semistructured interview with the project leader and asked the following four questions:

- How could NanoBio First achieve the early creation and exploitation of intellectual property, such as patent registration and licensing?
- What was expected of collaborations between a university and a startup in NanoBio First?
- What kind of actor had the high centrality as extracted from the network analysis?
- Why was another startup established after NanoBio First when one already existed?

These questions were selected as a result of narrowing the scope of the interview through examining publicly available documents such as postevaluation reports, field research such as preparatory interviews with project leaders and other key actors, and the results of our quantitative network analysis (see the next section), which showed that actors in startups have a high degree of centrality and betweenness centrality, and that collaboration between universities and startups plays an important role in the creation of intellectual property. This interview was conducted on 2 October, 2020.

4. Results

4.1. Network Analysis Based on Co-Inventor Network

The composition of the patent family created in NanoBio First used in the analysis is summarized in the Table 1.

Table 1. The composition of the patent family created in NanoBio First used in the analysis.

Researcher's Affiliation	Number of Affiliations	Number of Created Intellectual Property	Subtotal Number of Inventors
University	6	41 (15)	83
Industry	10	46 (19)	26
Public	5	12 (3)	17
Other	-	-	7

Note: each number of affiliations column represents a number of patent applicants or patentee per sector; a number of created intellectual property column shows a subtotal number of created patent families for each sector, where the counts overlap in the case of joint applications. The number of patent families filed in a single sector is shown in parentheses. The subtotal number of inventors columns represent the subtotal number of inventors listed in the patent document for each sector. The row of others represents inventors whose affiliation could not be identified from the patent documents.

The co-inventor network constructed with patent data from NanoBio First, as illustrated in Figure 2, had 133 nodes, 543 edges, and 10 connected components. One of the structural features of the co-inventor network we observed was that each cluster always included actors belonging to the industrial sector. Although some patents were applied for by only a single institute (university or public research institutes), cluster formation in the co-inventors network clearly showed collaborative relationships among inventors at NanoBio First associated with the product (i.e., patents); this indicated the synthesis of knowledge between researchers in academia and practitioners in industry. This suggests that actors who belong to the industrial area deliver knowledge to develop enterprises through R&D outcomes to actors who belong to academia, thereby serving as a complementary knowledge source.

Tables 2 and 3 list the top 25 actors with high degrees centrality and betweenness centrality, respectively. The actors with high degree centrality were researchers from a university, and were actively involved in the creation of the patents in this project. Furthermore, apart from university researchers, public research actors also had relatively high betweenness centrality. These actors were mainly principal investigators (PIs) at public research institutions, and they had higher betweenness centrality than degree centrality because they provide brokerage between members inside and outside of their organizations to collaborate with other organizations. Furthermore, as a common feature, only a few actors had high degree and betweenness centralities. The high centrality concentration of specific actors suggests that this co-inventor network had a core/periphery structure [71].

Notably, inventor 33, who belongs to the industrial sector, had high degree and betweenness centralities compared to other inventors in the industrial sector. Inventor 33 served as a chief science officer (CSO) for the university-originated startup founded by the project leader (see next section). Considering the intellectual property strategy in R&D projects based on university–industry–government collaboration, since this actor had a high centrality, in other words, was included in the core, the importance of the collaborative relationship between the university and startup was indicated. In fact, the startup to which this actor belonged filed many patent applications jointly with a university and contributed to the creation of intellectual property.

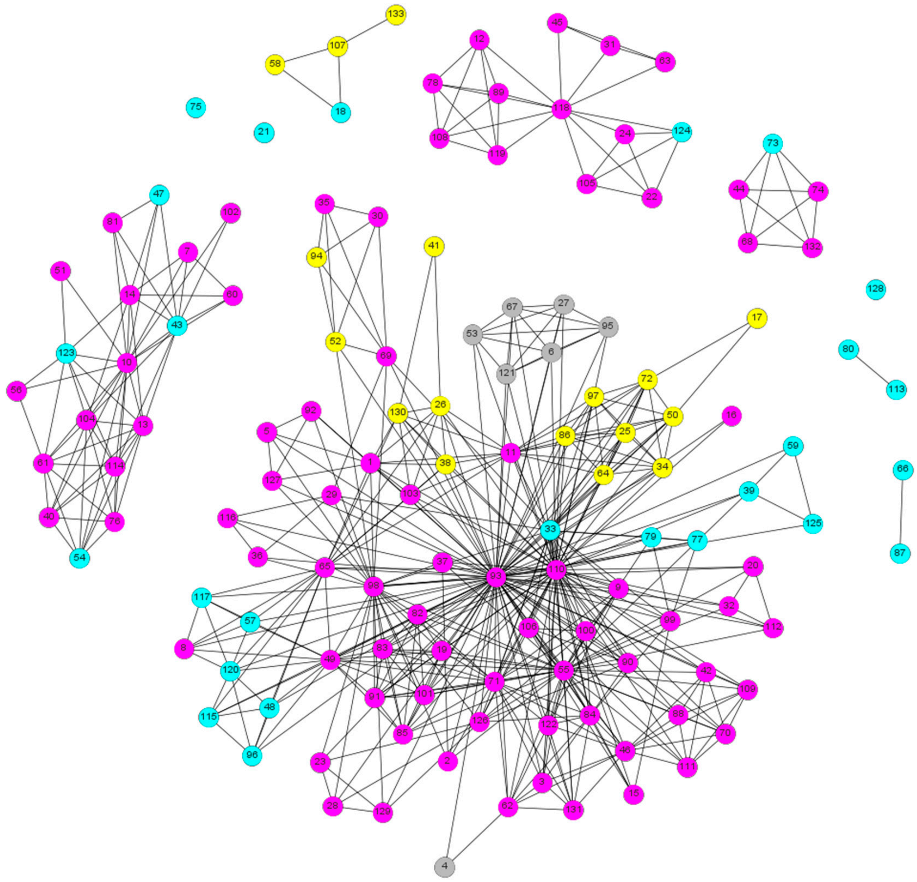

Figure 2. Network of co-inventors of patents created in NanoBio First. Each node is color-coded according to the sector to which the inventor belongs: purple, university; light blue, industry; yellow, public institute; gray, no data.

Table 2. Top 25 actors with high degree centrality in the co-inventor network.

Inventor	Sector	Degree Centrality
Inventor 93	University	80
Inventor 110	University	59
Inventor 55	University	37
Inventor 98	University	27
Inventor 33	Industry	25
Inventor 71	University	20
Inventor 49	University	19
Inventor 10	University	17
Inventor 11	University	16
Inventor 65	University	16
Inventor 84	University	16
Inventor 46	University	14
Inventor 1	University	12
Inventor 118	University	12
Inventor 122	University	12
Inventor 126	University	12
Inventor 19	University	11
Inventor 50	Public	11
Inventor 72	Public	11
Inventor 82	University	11
Inventor 83	University	11
Inventor 85	University	11
Inventor 91	University	11
Inventor 100	University	11
Inventor 101	University	11

Table 3. Top 25 actors with high betweenness centrality in the co-inventor network.

Inventor	Sector	Betweenness Centrality
Inventor 93	University	2025.55
Inventor 110	University	629.10
Inventor 55	University	140.94
Inventor 98	University	139.83
Inventor 69	University	135.97
Inventor 52	Public	107.70
Inventor 33	Industry	88.94
Inventor 10	University	57.25
Inventor 118	University	47.00
Inventor 26	Public	41.50
Inventor 50	Public	41.50
Inventor 72	Public	41.50
Inventor 130	Public	41.50
Inventor 49	University	39.00
Inventor 65	University	31.33
Inventor 11	University	20.92
Inventor 71	University	19.41
Inventor 1	University	13.67
Inventor 84	University	10.21
Inventor 43	Industry	10.20
Inventor 126	University	9.73
Inventor 46	University	7.50
Inventor 14	University	6.20
Inventor 123	Industry	4.95
Inventor 62	University	4.00

4.2. Qualitative Analysis of Intellectual Property Management

Table 4 is a summary of the semistructured interview questions and responses. First, the interviewed project leader had an unwavering mindset that outcomes of R&D can be made for societal benefit through patenting. By sharing this mindset, NanoBio First was able to achieve agile intellectual property management, such as publishing academic papers and applying for patents concurrently. Therefore, the fact that researchers at the NanoBio First closely consulted with a patent attorney hired using funds from the newly approved budget for R&D support for the creation of a "strong patent" capable of industrial application, even in the middle stages of the R&D, is thought to have led to the early commercialization of the intellectual property.

NanoBio First also adopted a strategy that emphasized collaboration with startups rather than existing large companies, such as licensing the intellectual property created by startups on a priority basis. The collaboration between universities and startups was expected to provide opportunities for researchers in academia to experientially learn the process of social implementation of their research outcomes and to function as a platform for the aforementioned mindset sharing. Although startups have limited resources compared to large existing companies, it seems that they were expected to act as collaborative partners for educational objectives such as the acquisition of tacit knowledge rather than benefits in terms of resources.

Table 4. Summary of semistructured interview's questions and responses to project leader.

Question	Observed Fact	Implication
Q 1: How could NanoBio First achieve early creation and exploitation of intellectual property, such as patent registration and licensing?	• The conventional patenting scheme is problematic because university researchers seek assistance with patenting from technology licensing organizations (TLOs) only during the final stages of R&D. • A researcher at the NanoBio first closely consulted with a patent attorney hired using funds from the newly approved budget for R&D support to create a "strong patent" which was suitable for industrial application, even in the middle stages of R&D. • Not only research leaders, but also practitioners should identify the similarities and differences between publishing and patenting their own R&D outcomes, which are not contradictory.	• Shared mindset that was recognized reciprocity between R&D and social implementation contributed to the rapid creation of intellectual property.
Q 2: What was expected of collaborations between a university and a startup in NanoBio First?	• Through collaboration with startups, it was expected that researchers in academia would experientially learn the seriousness of business and the process of implementing their own research results into society. • Interacting with existing large companies to provide the opportunity to undertake a real case study.	• The acquisition of tacit knowledge that can only be obtained through on-the-job-training in a real business environment was emphasized, rather than benefits in terms of R&D resources.
Q 3: What kind of actor had the high centrality (i.e., Inventor 33 in Figure 2) as extracted from the network analysis?	• Inventor 33 was the chief scientific officer of NanoCarrier at the time, and made important decisions regarding intellectual property; this individual had been the head of a research laboratory at a major biotechnology company prior to joining NanoCarrier	• A person who has dual skills in technological development and business administration played an important role in the creation and dissemination of intellectual property.
Q 4: Why was another startup (i.e., AccuRna) established after NanoBio First when one already existed?	• AccuRna was established as an organization to conduct R&D specializing in new modalities (i.e., nucleic acid drugs), which intended to concentrate the management resources. • NanoCarrier achieved the advancement of an anticancer drug (small molecule drug) under development to the clinical trial stage at that time, but R&D in a new field was undesirable due to the diversification of management resources and the risk of a backlash from investors.	• A new startup specializing in a new modality/application formed a specific intellectual resource pool that accelerated the product development process.

Inventor 33 was the chief science officer (CSO) at NanoCarrier, Co., Ltd. (Kashiwa, Chiba, Japan), which is a university-originated startup founded by the project leader before the commencement of NanoBio First project. Inventor 33 had previously worked at a large biotech company where he carried out research related to drug delivery (an expertise of the project leader), and was the director of the corporate laboratory there. Inventor 33 is a specialist with a deep understanding of intellectual property practices and their importance, and was one of the key decision makers on intellectual property serving as the CSO of NanoCarrier. This fact supports the suggestion from the results of the quantitative network analysis that a person who has dual skills in science and business administration plays an important role in the creation of intellectual property.

After the FIRST program, the project leader established a new startup, AccuRna Inc. (Kawasaki, Kanagawa, Japan), to focus resources on an R&D organization specializing in nucleic acid drugs, while an existing startup company i.e., NanoCarrier was already established. AccuRna entered into a capital and business alliance with NanoCarrier and set up a system to secure and utilize management resources in the early stages, and acquired exclusive rights to the intellectual property created in NanoBio First, which gave it a competitive advantage. In addition, the establishment of AccuRna was a great opportunity to attract people with expertise in nucleic acids or investors who are only interested in new technologies. This was expected to involve new stakeholders that NanoCarrier had not been able to approach in the past. In other words, talent was pooled into a new organization specializing in a specific domain, and the accompanying storage of knowledge tied to the person became feasible. The stored knowledge could be transferred from one organization to another through organizational consolidation, such as a corporate acquisition. AccuRna was finally acquired by NanoCarrier in September 2020, which integrated the human resources of both personnel and knowledge, such that knowledge transfer between organizations was achieved.

5. Discussion

5.1. Building a Knowledge Logistics System and the Contribution of a Startup

The results of the network analysis suggested that collaboration between actors from both academia and industry can promote the creation of intellectual property by synthesizing the complementary knowledge inherent in each sector. Hence, embedding such actors with complementary knowledge into the core in NanoBio First would accelerate knowledge sharing [72], and forming a transaction-free zone [73] would facilitate efficient knowledge exchange across the sectors. Reduced communication costs within a core would accelerate the R&D cycle and efficiently create R&D outcomes [9,74].

On the other hand, the results of the interview indicated that researchers were encouraged to acquire practical knowledge (mindset, business diligence, skills, and know-how) on the creation of intellectual property, as well as on its social implementation, through on-the-job-training [75] within a startup. In other words, NanoBio First prioritized human resources skilled in both science and business administration [76]. To cultivate such talent, NanoBio First highlighted the transformation of the mindset of researchers in academia. In this study, we define the terms “sequential mindset” and “reciprocal mindset” to distinguish between mindsets that should be rejected and those that should be cultivated in such a transformation. A sequential mindset is a mode of thought assuming that technology and knowledge transfer proceeds from basic research to applied research and development in stages, as in a linear model of innovation, and that social implementation is not considered until the final stage of research and development. Meanwhile, the reciprocal mindset is a mode of thought that actively seeks to acquire and store tacit knowledge in domains closer to social implementation to achieve the concurrent creation of academic and practical outcomes with consideration to the interaction between R&D and social implementation. The significance and benefit of cultivating such a reciprocal mindset contributed to the early acquisition of “strong patents” suited to industrial applications.

To summarize the above discussion, NanoBio First incorporated a process of learning to acquire explicit and tacit knowledge across different domains and sectors. A rapid knowledge production cycle in the transaction-free zone inside the core brought about the development of a knowledge logistics system for the agile generation of “strong patents” and the early creation of intellectual property. In particular, the involvement of the startup NanoCarrier was crucial in the implementation of the above-mentioned system.

5.2. *Information Asymmetry in Intellectual Property Management*

The present study focuses on the principal–agent relationship [47] caused by information asymmetry between knowledge producers (project body) and knowledge consumers (industry or program body as a mediator) in knowledge logistics, and considers the possibility that conflicts of interest impede the efficient creation of intellectual property. In this assumption, the knowledge consumers correspond to the principal and the knowledge producer to the agent; the agent has either a sequential or a reciprocal mindset, i.e., private information that the principal cannot observe directly. Figure 3 shows a schematic representation of the payoff relationship between knowledge producers and knowledge consumers based on the framework of the principal–agent model. When information asymmetry exists in the process of intellectual property creation, the principal–agent relationship can cause problems, such as adverse selection and moral hazard.

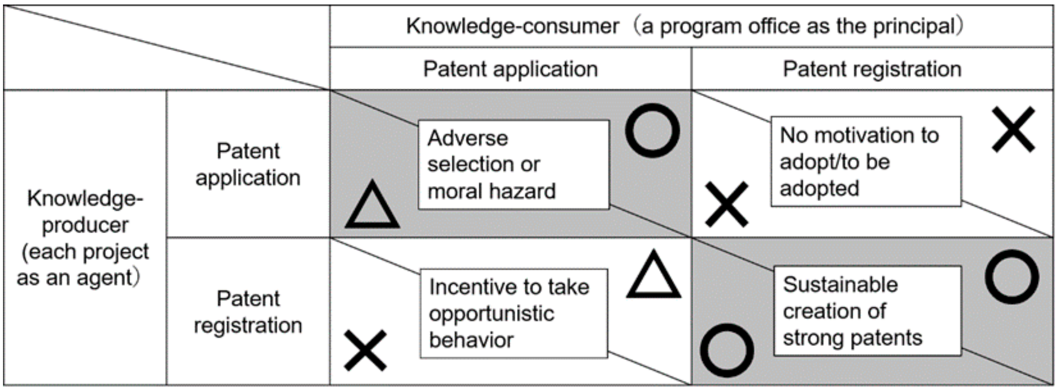

Figure 3. Schematic diagram of the payoff relationship in the principal–agent relationship between knowledge producers and knowledge consumers. A circle in the symbol indicates that it is a beneficial choice for the relevant principal or agent's stance, a triangle indicates that it is difficult to determine either, and a cross indicates that it is an unbeneficial one.

5.2.1. Utilization of a Startup for Preventing Adverse Selection

When principals evaluate whether an agent will appropriately create intellectual property under information asymmetry, they tend to use the number of patent applications as evaluation criteria, because patent registrations require a certain amount of time and involve additional costs and uncertainty. Based on this criterion, agents with a sequential mindset tend to be judged as superior to those with a reciprocal mindset, which would be desirable for the creation of intellectual property, rather than because of the larger number of patent applications. Therefore, there is a problem of adverse selection. In the worst-case scenario, agents with a sequential mindset drive out agents with a reciprocal mindset, resulting in a flood of patents that are unsuitable for industrial use.

In general, there are two measures to prevent adverse selection: screening and signaling. In a case like the FIRST Program, the establishment of a startup before calling for projects can contribute to both. Specifically, screening corresponds to designing R&D programs with two types of grant plans: a plan in which only projects that have been undertaken through industry–academia collaboration with established startups obtain a generous budget and support; and another plan in which projects require little effort for commercialization but have a limited budget and support. This would prevent the adoption of projects that have little interest in the social implementation of R&D outcomes. Simultaneously, signaling agents' "seriousness" about innovation through the establishment of a startup offers a useful measure of the value of investment to the principals.

5.2.2. Monitoring and Incentive Mechanisms for Avoiding Moral Hazard

Owing to information asymmetry originating from highly specialized knowledge, another problem, namely moral hazard, can arise between principals and agents in cutting-edge R&D projects. Even if an agent displayed opportunistic behavior, for instance, by submitting an application without requesting patent prosecution, the principal would not know the reasons in detail without understanding the content of the individual patents, which requires highly specialized knowledge. Hence, agents would have a strong incentive to select such opportunistic behavior because achieving patent registrations requires money and effort, not only at the time of patent application, but also at the time of patent prosecution request.

To prevent moral hazard, it was effective to cultivate a reciprocal mindset for social implementation. In addition to this, enhanced monitoring and incentive contracts would also be effective. In the FIRST Program, milestone evaluations such as periodic monitoring were conducted, which contributed to prevention of moral hazard to a certain degree. However, program designers should be aware of the limitations of monitoring enhancement offered by the increasing size and complexity of an R&D project. On the other hand, a simple incentive contract ensures that only projects that actively create intellectual property receive additional R&D funding.

To exercise these measures properly, a mechanism design must satisfy the incentive compatibility for agents. For young researchers, for example, contracts that lead to stable employment, such as offering permanent posts and priority hiring, will be able to provide stronger incentives than financial induction because there is a certain amount of risk involved in engaging in activities for the creation of intellectual property instead of academic research [10].

5.3. Implications to the SDGs

Transdisciplinary R&D is an inclusive concept to solve the outstanding complex challenges regarding SDGs through interdisciplinary knowledge integration and the involvement of professional and social stakeholders outside of academia [36–40], where the program and project management discussed in the present paper are necessary to optimize the intricate coordination and conflicts among stakeholders.

The FIRST program was a key governmental R&D initiative of Japan oriented toward the promotion of sustainable development that potentially addressed a full range of SDGs. Among those, NanoBio First was a particular project case that aimed to build a health care system with compatibility between the health and quality of life of patients, which is expected to contribute to Goals 3 and 9 in their current interpretation. Therefore, investigating the collaborative structure among academic, public and industrial actors through an in-depth case study can be expected to facilitate substantial value creation, and thus, deserves broad application in project management in the future.

One theoretical implication of the present study is that bridging the gap between two scholarly streams, policy science research and management science research, allowed us to develop a methodological basis for dealing with program and project management measures in an integrated manner, based on a mixed-methods approach. In addition, from the perspective of principal–agent theory, the mechanisms that promote and impede the creation of intellectual property in large-scale R&D projects were explained. Meanwhile, one practical implication is the contribution to the institutional design of future R&D programs and projects regarding SDGs. The utilization of startups and the incentive design for sustainable intellectual property creation were highlighted, especially in transdisciplinary research and development.

5.4. Limitations and Future Perspectives

The present study has several limitations. First, generalizability cannot be guaranteed because the present study based its theory upon a single case study. Further theoretical development is expected by expanding the applicable object to other R&D programs or projects in the future.

This requires the availability of data for comparative analyses among different cases. In other words, policy-makers should be aware of an institutional design that makes it possible to conduct analyses of so-called evidence-based policy making after the completion of an R&D program or project. Second, since the present study intended to reveal a mechanism that promotes or impedes the creation of intellectual property, the proposed model that explains adverse selection and moral hazard in the process of creating intellectual property is not mathematically rigorous. A mechanism design for mission-oriented R&D program or project will require a mathematically rigorous approach. The development of mathematical models representing incentive mechanisms could also contribute to empirical analyses (e.g., statistical analysis) for the process of intellectual property creation. Third, the R&D outcomes, such as trade secrets or know-how, that are strategically hidden to prevent imitation by competitors, were not considered because the present study mainly analyzed patent information. To consider more strategic decision-making, the proposed model should modify the behavior or types of players. An improved model will facilitate analyses of decision-making in more complex situations. In addition, to deal with realistic decision-making processes, or to avoid the bounded assumptions of players in principal–agent theory (or game theory), introducing a psychological or behavioral economic approach to the analysis would be desirable.

6. Conclusions

To reveal the mechanisms that promote or impede the creation of intellectual property in a large-scale, publicly funded R&D project oriented toward SDGs, we performed a case study using a mixed-methods approach, combining quantitative and qualitative analyses. Focusing on the FIRST Program, which is a national initiative promoting innovative and world-leading R&D, we chose NanoBio First, as it demonstrated the best practices in terms of intellectual property creation. A quantitative analysis using patent data indicated that the co-inventor network had a core/periphery structure, and the return of intellectual property to society was promoted through joint applications with a startup with a complementary role of the university. Our qualitative analysis of the management policy on intellectual property confirmed that the project leader emphasized cultivating university researchers' mindsets towards social implementation through collaborations with startups, and to establish systems for flexible resource management according to the R&D stage. Based on these results, using the framework of principal–agent theory, we modeled the decision-making process with information asymmetry between knowledge producers and knowledge consumers to devise a systematic explanation of the mechanism that promotes or inhibits the creation of intellectual property in large-scale R&D projects involving diverse actors. To handle adverse selection and moral hazard in the process of intellectual property creation, we discussed the effectiveness of solutions, such that agents should plan the R&D strategy, including collaboration with a startup at the time of project adoption. Moreover, principals should stipulate incentive contracts that provide additional R&D funding depending on the degree of intellectual property creation.

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