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New public-private partnership based on the interactive collaboration in the space sector

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ABSTRACT

This paper presents a new open innovation type of public-private partnership (PPP) to create a space industry, in which innovative technology development by the public R&D sector and space business creation by the private sector are simultaneously realized through bi-directional collaboration between the public and private sectors. This PPP type is a solution to the issues pointed out in previous studies, namely, the relative reduction of R&D opportunities for the public sector due to technological assistance to the private sector, and the decline in technological performance due to risk aversion in the private sector. Next, we present an evaluation method for this collaborative partnership based on the evaluation indicators for value co-creation research. Finally, to identify the process factors driving the projects in this PPP type, we surveyed about 30 space PPP projects in the Japanese space sector implemented since 2018. Then, the results of the qualitative comparative analysis (QCA) revealed that the factors are the estimation of mutual capabilities and benefits, the establishment of collaboration goals, and the commitment to mutual activities. The findings suggest that it is possible to define a new space PPP type that complements the space PPP typology of previous studies, and that it is possible to promote this space PPP project through appropriate management of two-way collaboration.

1. Introduction

The space industry is a comprehensive industry with a wide range of related industries and is approaching the next frontier. It is estimated that the global space economy will be worth $1.8 trillion by 2035, taking inflation into account, up from $630 billion in 2023. This figure includes applications such as those for satellites, launchers, and services like broadcast television or GPS. It also includes applications for which space technology helps companies across industries generate revenues [1]. In order to further expand the space industry, it is desirable for private companies to take the initiative in developing and operating businesses with a high degree of freedom and on their own initiative. However, space system development generally involves the development of new technologies, which cannot be repaired, modified, or redone after launch into space. Therefore, design, development, launch by rocket, operation, asset maintenance, market, and residual risk are more severe than in other sectors. Since it remains difficult for private companies to create their own space business on their own, public-private partnerships (PPPs) between private companies (referred to as private in this paper) and public research and development (R&D) agencies (referred to as public in this paper) that have been engaged in R&D and national projects have been promoted in Europe and the United States [2]. In order to collaborate with private companies seeking to create business in an agile manner, NASA has also seen efforts to adapt to flexible change and transform itself into an agile agency [3]. Kim [2] summarized the differences between PPPs in the general sector and PPPs in the space sector, and then classified Space PPPs into four Types according to the different roles of the public and private sectors. Then, the usefulness of this typology was demonstrated using case studies of several space flight and launch service programs in Europe and the United States.

On the other hand, the more the role and risk sharing of the private sector is large in the Space PPP, the more the private sector tends to avoid technical risks and the technical performance of the space business declines [4]. Correspondingly, if the public focuses on providing technical support to the private sector, the R&D opportunities for the public sector may shrink relatively, making it difficult to accumulate knowledge and expertise [5].

Furthermore, in the case of Japan, there are a major difference compared to the U.S. Japan Aerospace Exploration Agency (JAXA), a national R&D agency, has a smaller technological base, budget, and

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human resources than NASA and other agencies. Many private companies proceed with business creation on their initiative based on their own business ideas and technologies, and as a result are often faced with technological challenges. If JAXA focuses its resources on technical support to the private sector, JAXA's research, development, and utilization and its response to national projects will be relatively reduced, which may affect its capabilities to consider future challenging missions more than in the United States.

Therefore, it is important to search for a method to create a private space business with high technological performance through appropriate collaboration with the private sector, while the public is responsible for the realization of national projects and necessary R&D.

Based on the above background, this paper presents a new Space PPP Type, which complements the four types of Space PPP typology presented by Kim [2,4], based on Japan's efforts to create space businesses. This new type is an open innovation type of interactive collaboration between the public and private sectors, in which the public acquires new core competencies in technology, proposes value proposition to the private sector, contributes to solving their technological problems, and aims to create their unique business opportunities. Furthermore, the public sector will obtain feedback from the private sector to promote further technological development.

Next, new evaluation indicators for this Space PPP was established. Then, we clarified the process factors for the progress for about 30 Japanese projects belonging to this Space PPP type to which the author had access to information. Japan's Space Industry Vision 2030 [6], established in 2017, aims to double the market size of the entire space industry in Japan, including the space utilization industry, in the early 2030s through the expanded role of the private sector. In 2018, the Japanese government also announced a new support package for space venture development [7]. JAXA set "Space Utilization Expansion and Industry Promotion" as one of the pillar measures in JAXA's Fourth Medium- and Long-term Plan starting in FY2018 [8], and JAXA has started to collaborate with the private sector to create space businesses. About 50 of these projects are collaborative projects that have been promoted under this JAXA's Fourth Medium- and Long-term Plan. But it is not easy to simultaneously create a private space business with high technological performance and acquire core competence in public R&D. If the space PPP does not function and the space industry is not expanded in response to expectations, there is a risk of stagnation and dysfunction of investment and expectations for this space sector in the future. Therefore, it is important to understand the process of building and promoting the Space PPP projects. However, there are very few empirical studies that specifically capture changes in the Space PPP projects over time and question the relationship between process factors affecting the progress and outcomes. There are also very few studies on evaluation indicators for Space PPPs. Therefore, in this paper, in order to understand the status of interactive collaboration in each Space PPP project, we define services as the application of specialized competences (knowledge and skills) through deeds, processes, and performances for the benefit of another entity or the entity itself [9] through interaction with customers to solve customer problems and create value. Then, we conducted literature review on service research, where value co-creation has been mainly discussed, and organized the latest perspectives and findings on evaluation indicators. Next, based on these, we established evaluation indicators for this Space PPP. Using these indicators, we analyze the temporal changes in the status of the public, private, and public-private partnerships, and seek to understand the factors that influence the progress of each PPP collaborative project.

2. Literature review

2.1. Space PPP typology and impact on outcomes

We conducted a literature review by Google Scholar and Elsevier using the keywords Public Private Partnership, Space Industry, Space Program, and Typology to review articles on Space PPPs. Then a total of 17 papers were selected as the main articles and cited articles related to the evaluation of Space PPPs.

The results can be divided into three main categories. The first category summarizes the differences in characteristics between the space industry and general industry, and points out issues in applying the typology and evaluation methods of PPPs in other sectors to space PPPs. The second category presents the typology of space PPPs. The third category attempts to extract and evaluate the results of the Space PPP method through comparison with the traditional government procurement method.

The first category of previous studies posits that three economic theories are involved in PPP arrangements in the general sector [2,10–12]. The first theory posits that in PPPs, more efficient resource allocation occurs through bilateral transactions based on comparative advantage. For example, production processes in which the private sector has a comparative advantage are outsourced by the public sector to improve the production efficiency of the public sector. The second theory states that in PPPs, incentives are secured by bundling tasks. For example, if development/manufacturing and tasks such as operation are performed by different parties, the development/manufacturing firm will have no incentive to improve the quality of products in the operation phase [2,10,13,14]. On the other hand, if the same party performs both tasks, there is an incentive to maximize investment in the manufacturing process, which reduces operational costs and improves overall efficiency [2,13,15,16]. The third theory states that in a PPP, there is an appropriate sharing of risks and rewards by the public and private sectors. Some risks are endogenous to the private sector but exogenous to the public sector and vice versa [2,14]. And, in general, the party better able to manage the risk should bear the risk and be rewarded for doing so [2,12,14]. These are the advantages of PPPs over traditional procurement and commercial development methods, in which a single party, either public or private, bears all risks. However, theoretical advantages are not always guaranteed in practice. But Bertran and Vidal [17] note that compared to more general sectors such as education, transportation, hospitals, water supply, and infrastructure, the space sector has more significant design, deployment (including rocket launch), operational, asset (especially space asset) maintenance, market, and residual value risks than any other sector, and the risks allocation methodology in typical PPP does not apply to that in Space PPPs.

Regarding the second category of previous studies, Hashimoto [18] classified space PPPs into two types based on the general PPP typology, according to the PPP phase and the division of roles: In the first type, the government conducts the planning, research, development, demonstration, and initial operation of the project using public funds, and if the project is expected to be profitable, it is transferred to the private sector in the operation phase. This is a steady collaboration method, but it is not a type that creates a business unique to the private sector. The second Type is a collaboration in which private plan, research, develop, demonstrate, and operate new businesses mainly with their own funds, and the government provides continuous technical support from the business planning stage, contributing to the efficiency and risk reduction of private business creation. Hashimoto [18] further subdivided the above two types by focusing on the difference in whether the customer is the public or private sector. In contrast, Kim [2] raised an alarm at the point where many PPPs are adopted in the absence of critical academic discussion on the effectiveness of space PPPs, with the expectation of replicating the outstanding cost and schedule performance of the Commercial Orbital Transportation Services (COTS) Program to the ISS. He then surveyed the Types of space PPPs in previous studies and more than 10 PPP projects in the space sector in Europe and the U.S. over the past 20 years, and encompassed the two Types of Hashimoto [18] into four Types according to the public-private division of funds, project design and development, and ownership and operation of the created projects. Specifically, 1) TYPE 1: Operation Concession (OCon), 2) TYPE

2: Partially Finance-Design-Develop (PFD), 3) TYPE 3: Partially Finance-Design-Develop and Fully Own- Operate (PFD-FO), and 4) TYPE4: Partially Finance and Fully Design-Develop-Own-Operate (PF-FDO) [2,4]. The later the TYPE, the more risk and business freedom the private sector has; the two TYPEs in Hashimoto [18] correspond to TYPE1 and TYPE4 above. Although this typology is primarily an academic tool, it can increase transparency among PPP stakeholders through mutual understanding of incentives, objectives, roles, responsibilities, risks, and rewards. Space agencies will be able to be more specific about the type of PPP they wish to have when requesting information and proposals, and private will be able to reduce ambiguity and understand the nature of the partnership they seek. On the other hand, this typology of space PPPs is currently in the exploratory stage in its original form, and empirical research on the outcomes of various space PPPs is needed. Also, taking into account differences in access to capital markets and public-private relationships in each country, the possibility of more effective PPP typologies in specific countries remains [2]. Kim [2] also suggested that a new Type may emerge as Space PPPs mature.

With respect to the third category of previous studies, we found only four papers on the evaluation of Space PPPs; Karen L. Jones [19] found that in the United States, a type (TYPE4) in which private companies use NASA-owned intellectual property to create their own businesses has advanced, and NASA has developed an appropriate framework to support this [20,21]. And although COTS was considered to be a good example, at this point, only a summary of the status of collaboration and major results has been organized. Zapata [22], also using COTS as a target case, showed the difference between the conventional public procurement method and the Type 4 PPP method in terms of cost and delivery time improvement. However, the only case study covered is COTS, and the main evaluation indicator is cost and schedule. Mazzucato [5] showed the change in NASA's efforts in Low-Earth Orbit (LEO), particularly the International Space Station (ISS), from traditional public procurement efforts to building an ecosystem model of LEO economic activity. NASA procures and mediates private services, NASA is responsible for extracting private investment through the use of NASA's intellectual property, and for R&D investment in small and medium-sized enterprises. However, it does not include an evaluation of the specific outcomes of the collaboration. Kim [4]) evaluated the cost, schedule, and technical performance of the private space business created by the Space PPP. However, at this point, the evaluation is limited to semi-structured interviews with six experts in the field of space business and an analytical evaluation of the results. Mariana Mazzucato [5] also pointed out that in space PPPs, when the role of the public official is mainly technical support based on the existing technology and knowledge possessed, the organizational capacity can be reduced as it does not involve the realization of the public official's own mission and the continuous strengthening of R&D necessary to consider new challenging missions [23]. Kim [4] also pointed out that in space PPPs, the private sector generally tends to be risk-averse and the public sector tends to be more involved, and that a shift in sharing to the private sector would lead to a decline in technical performance as the private sector avoids technical risks. However, previous studies have found few evaluations of the outcomes and performance of private space business through PPPs and their impact on public R&D activities. In addition, there are no previous studies that give a perspective on the process factors themselves that affect the progress of Space PPPs.

The research theme of this paper is the type of space PPP that will generate private-sector projects with high technological performance while also enhancing the R&D capacity of the public sector, and the process factors that will facilitate the progress of this space PPP.

2.2. Evaluation indicators for service research perspectives

In order to evaluate space PPPs, it is important to target not only the final outcome of the collaboration, but also the entire process of partnership to understand the process factors that affect the status of the collaboration. However, as indicated in section 2.1, few such previous studies have been found, and even in some cases, the evaluation is limited to final and superficial outputs such as costs and schedules. The reasons for this are that there are few examples and information on Space PPPs, making it difficult for non-parties to access information on actual collaboration, and that evaluation indicators for Space PPPs have not been organized.

For the purpose of organizing evaluation indicators, this paper regards services as activities in which the public applies cutting-edge R&D results to solve the problems of the private sector. Then, we organize the latest perspectives of service research, mainly in the B2B fields, where value co-creation between service providers and service recipients is mainly discussed, and findings on evaluation indicators. Then, based on these, we will set evaluation indicators for Space PPPs and attempt to analyze each Space PPP collaboration project.

Based on the above approach, we searched for review papers on value co-creation using Web Of Science and Google Scholar, and selected a total of 25 major papers and related cited papers that includes the keywords to the main perspectives such as Service Management, Service Design, and Service Innovation obtained from the review papers, added new related papers, and organized the findings regarding the theory, evaluation indicators, and capabilities of service providers and recipients.

The above previous studies can be divided into two main categories: the first category mainly organizes the latest theories of value co-creation and presents a perspective on value co-creation and value co-destruction; the second category presents evaluation indicators and evaluation results based on this theory.

With respect to the first previous study category, the service dominant logic (S-D logic) defined service as "the utilization of action, process, and competence through interaction with customers to solve their problems and create value [9]". Service providers integrate resources with customers and emphasize the co-creation of customer use and contextual values through dialogue, interaction, and transparent activities [24–31]. Plé and Rubén [32] also pointed out the possibility of value co-destruction as well as value co-creation through interactions between service systems and organized the process by which value co-destruction occurs. Plé and Rubén [32] showed that the interaction between different systems can cause accidental or intentional misuse of resources, resulting in value destruction, and proposed that in practice, mutual expectations should be matched to reduce the risk of value co-destruction, and that recovery from the risk should be considered. Based on the above, we believe the following three points need to be taken into account in order for the public to create new technological achievements and transform them into use and contextual values for the private sector (which shall be the customers) aiming at space business creation: (1) a value co-creation system that integrates strategies and plans of both public and private sectors, (2) the value creation process and interaction situation between public and private sectors, and (3) actual results of collaboration.

Regarding the second previous study category, evaluation indicators, Krista Keränen [33], focusing mainly on B2B co-creation projects, assumes that co-creation is a central concept in service marketing and management, service design and innovation, and sets three evaluation indicators to observe co-creation activities. The first indicator was set as "Strategic Thinking and business model" [34,35]. This indicator covered the discussion of S-D logic and specified sub-indicators on goals, strategies, processes and resource utilization [36]. The second indicator was set as "Customer interactions and relationships. This indicator covers the discussion of co-production of services [37] and specified sub-indicators regarding the quality and quantity of relationships between firms and customers. Then, the third indicator covered the knowledge of Service Design, including the concept of service innovation [38–40]. Sub-indicators were defined for the collection [41] and processing of customer information and the status of the Value Proposition according to the progress of each collaboration phase. Krista Keränen [33] conducted a case study analysis of B2B service businesses using these three indicators. She showed the difference between traditional and co-creation business approaches, and encouraged companies to increase their awareness of co-creation and shift to a co-creation approach. Javier Marcos-Cuevas [42] also focused on the value co-creation process [24], and highlighted "organizational practices for collaborative value co-creation" through resource integration [28], and "organizational capabilities for collaborative value co-creation" [43], which allow practices to emerge. He also pointed out the importance of identifying “compelling events”, “sense and seize opportunities for value co-creation [44]”, “calculations of the benefits that can mutually be created [45]”, “sustained purposeful engagement [45]” for the realization of value co-creation. Then, using this indicator, case analyses were conducted for several B2B co-creation projects, such as an aircraft engine operation business, to organize the ways in which the service provider’s capabilities are acted upon and strengthened, and to capture changes over time in the collaboration. In the S-D logic, not only service providers but also service recipients play an important role in service value creation and service interaction [9,24,46]. Therefore, it is also important for service recipients to improve their capabilities in order to innovate services and maximize their value.

Based on the perspectives of the previous studies mentioned above, the following evaluation indicators for Space PPP, the subject of this paper, are considered important: (1) identifying opportunities for collaboration, estimating mutual capabilities, and setting collaboration strategies and goals, (2) methods and management for sustaining proactive and objective-oriented interactions, and (3) assessment of the value provided to the partner and the creation of collaborative outcomes.

From the above, the research theme of this paper is to determine what is the evaluation method for Space PPPs that will generate private-sector projects with high technological performance while also enhancing the R&D capability of the public sector.

3. Method

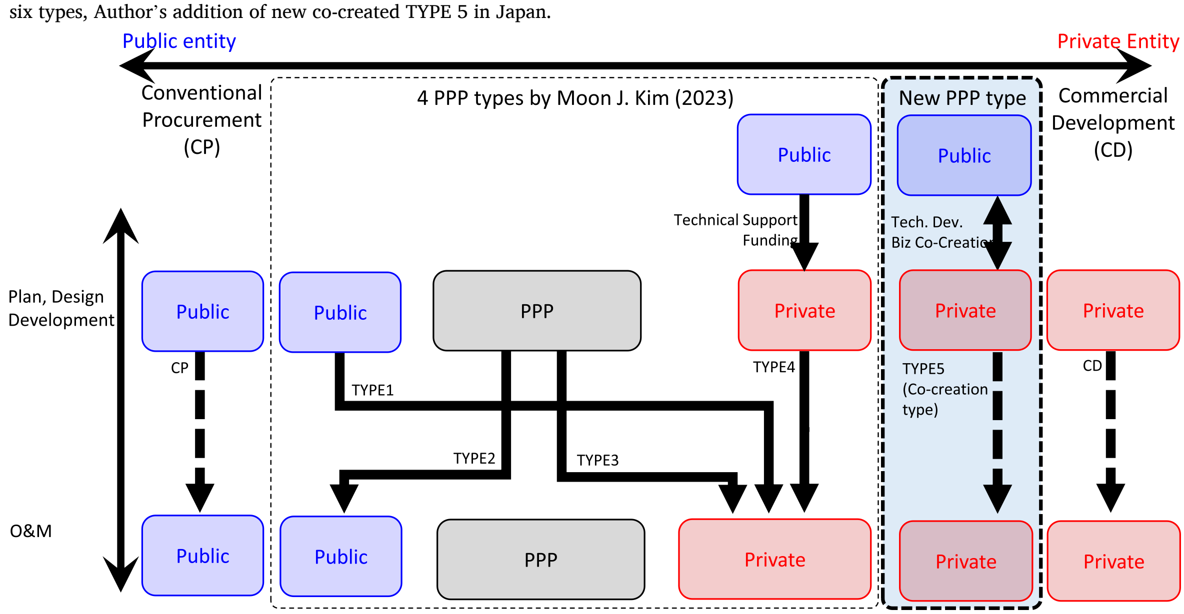
3.1. Survey design and data

This paper presents a new Space PPP TYPE5, Fully Finance and Fully Design-Develop-Own-Operate with Co-Creation type (FF-FDO-C) based on the status of Japan’s efforts. It is a complementary type to the six types proposed by Kim [2,4], including four types of space PPPs (TYPE 1–4) and two types of non-space PPPs (Conventional procurement type and Commercial development type). This TYPE 5 aims to create a private space business with high technological performance while the public sector is responsible for the realization of challenging national projects and necessary R&D. As such, it addresses the issues identified by previous studies and the constraints of Japan’s resource and technology base. In terms of the division of roles between the public and private sectors, the TYPE5 is positioned between TYPE4 and the Commercial development type, and complements these two types. As in TYPE4, the public sector will address the technical issues of the private sector in TYPE5. However, unlike TYPE4, which provides technical support based on existing technological infrastructure, in TYPE5, the public sector is responsible for new technological development in line with its own R&D strategy and collaborates with the private sector based on such development results. In addition, the public does not provide financial support to the private sector for their business creation, and the public funds are used for its own R&D activities. Type5 is intended to be effective for other countries in the space sector when public does not have sufficient technological infrastructure, financial and human resources, and when it is necessary to maximize performance to deal with the situation where public is developing its own technology and public projects while also creating a private space industry.

The TYPEs located on the right side of Table 1 are those in which the private sector plays an increasing role and the business risk is higher. However, it is desirable from the viewpoint of expanding the space industry because it allows for greater freedom and flexibility in business. In this paper, we focus on this co-creation TYPE 5, set evaluation indicators, and summarize the conditions that lead to successful collaborative projects.

Next, we organized the indicators for evaluating each PPP project in the new co-creation TYPE 5. Based on the evaluation indicators for value

Table 1
The four types of space PPPs, procurement types, and private-sector types, as summarized by Moon J. Kim May 2023, compared to a total of six types, Author’s addition of new co-created TYPE 5 in Japan.



co-creation, mainly for B2B, in the results of previous studies in section 2.2, we made modifications by the following way.

- Addition of indicators based on the latest results of previous value co-creation studies.
- Modification of indicators to take into account partnership between public and private sector.
- Simplification of complex and duplicated sub-indicators.

Based on the above way, evaluation indicators for the Space PPP TYPE 5 are presented in Table 2.

Next, among the approximately 50 projects of TYPE 5 Space PPP between Japanese private companies and JAXA since 2018, a total of 31 projects were selected for evaluation, for which the author had access to information and could judge some progress in terms of achievements. These projects have been implemented under JAXA Space Innovation Partnership Program, named J-SPARC [47], a Space PPP, in accordance with Japanese policy [6,7]. Furthermore, of these 31 projects, 24 projects were selected as those for which the progress of the private sector's business can be judged. The seven projects in the difference are those for which it is possible to judge the progress of the public sector's technological achievements, but it takes time for the private sectors to make progress on their business achievements, and the judgment is premature. In addition, the survey was conducted by dividing the target projects into two categories: 1) launch vehicle, satellite, and component projects involving the launch of hardware into space, and 2) ground-based deployment projects utilizing satellite data and intellectual property accumulated on the ground. Space system development generally involves the development of new technologies, which cannot be repaired, modified, or redone after launch into space, and the design, development, launch by launch vehicle, operation, asset maintenance, market, and residual risks are more severe than those in other fields [2,4]. For this reason, it is considered appropriate to conduct separate analysis and evaluation for projects that involve launches and those that do not.

In general, it is difficult for outsiders to obtain information on the business strategies and plans of the private sector, the R&D strategies and plans of the public sector, and the status of collaboration between the public and private sectors in each Space PPP project. Therefore, the design and implementation of the survey relied heavily on the first author's practical experience as a business producer at JAXA, his second affiliation, as well as his personal network with other business producers at JAXA. The author has experience as a business producer at JAXA and has participated in the review and meetings of each cooperative project, and the above 31 projects surveyed in this paper include those in which he was involved as a business producer. The reason for including each Space PPP project in the analysis, rather than information aggregated by organizational unit, is to capture differences based on the self-discretion and emergence of business producers [48].

Based on the above, a summary of the selected projects to be evaluated is organized in Table 3. Projects that resulted in the creation of a private business and those that were interrupted in the process, as well as those that achieved R&D results and those that did not can be confirmed as being included in the analysis.

Next, criteria for each indicator were established to determine the achievement status of the evaluation indicators shown in Table 2 above. The business producer assigned to each PPP project handles everything from the promotion of dialogue between the public and private sectors, to the creation of project concepts, to the promotion of demonstration and commercialization. The criteria for A2, "Mutual Capacity Estimation and Mutual Benefit Estimation," were set in two parts, since it mainly involves confirmation of both the public and private sectors. The list of criteria developed is shown in Table 4.

The structured questions in Table 4 were then coded as 1 if the answer was "yes" and 0 if the answer was "no" based on the facts. For coding, JAXA and private companies' review meetings, various meeting materials, records, and publicly available information were used for each project. In addition, semi-structured interviews were conducted with the JAXA's business producer in charge of each project to confirm the information. In this way, we tried to confirm the reliability of the coded data and enhance objectivity. In order to take into account the different attributes of each space business, T1 is set to a value of "1" if the business idea utilizes space, which is generally more difficult to create. In the case of business ideas utilizing space data and knowledge on the ground, T1 is set to a value of "0". In all cases, the public collaboration party is JAXA's R&D personnel.

OUT1 is defined as "1" when private companies participating in the

Table 2
Evaluation indicators for analyzing the new co-created space PPP projects proposed in this paper based on previous studies.

Valuation index	Sub-indicator		
	Item	Contents	Relation to Previous Studies
A. Strategic Thinking, Collaborative Models	1 Sense Opportunities	• Perception of competing events	• Sense value co-creation opportunities • Strategic process (Bottom-up/Outside-in)
	2 Mutual Capabilities/ Benefits Estimation	• Clarification of collaboration capabilities (resources) • Estimate benefits/risks of collaboration and determine feasibility	• Resource Integration • Mutual benefit estimation
	3. Collaboration Goal setting and commitment	• Both recipient and provider set goals and Both parties commit	• Goal (customer solution, value-in-use co-creation)
B. Interaction	1. Interaction Management	• Ensuring the ability to carry out interactions • Interaction promotion function and value co-destruction prevention function	• Collection and processing of information about customers • Strategic management of interaction capacity and practice status
	2. Interaction Processes	• Specifying the Interaction Process • Initiation of interaction	• Value creation process (understanding customer information, customer value creation focus)
	3. Interaction Outcome	• Stabilization of interactions associated with the creation of collaborative outcomes and Sustained involvement of both parties • Mutual identification and response to potential factors leading to value co-destruction	• Proactive interaction characteristics, purposeful and sustained engagement • Customer access to information and other resources
C. Collaboration Content, Outcomes	1. Provider Activities	• Strengthening Core Competencies through Collaboration with Recipients • Providing Value Propositions to Receivers	• Value Proposition development, testing and service launch
	2. Recipient Activities	• Improving receptivity to value through collaboration with providers and Creating new businesses • Contribution to strengthening the core competence of the provider	• Improved service literacy of recipients

Table 3
Co-creation project activities analyzed by business area in Japan (April 2018–January 2024).

Case	Private Business Evaluation Cases			Public R&D Evaluation Cases		Total number of cases
Business Area	Achieved	Not achieved	In process	Achieved	Not achieved	
1) In Space (Rocket/Satellite/Components)	8	5	7	**14**	**6**	20
2) On Earth (Data Utilization, etc.)	7	4	0	**6**	**5**	11
Total	15	9	7	**20**	**11**	31

Table 4
List of criteria corresponding to evaluation indicators for TYPE 5 space PPPs.

NO	variable	criteria
A1	Sense Opportunities	• The private sector makes decisions on commercialization activities based on market research and requires the public sector to respond to technical issues.
A2-1	Mutual Capability/ Benefits Estimation for Public	• The base public technology consists of applied research stage or higher.
A2-2	Mutual Capacity/Benefit Estimation for private	• Private sector business plans are being developed by utilizing technology owned/ to be owned by the public sector.
A3	Collaboration Goal setting and commitment	• Collaboration goals have been set, but to strengthen commitment, public R&D activities are defined separately from private sector activities, within the scope of existing plans.
B1	Interaction Management	• Public-private collaboration venues and tools are in place to promote and manage collaboration.
B2	Interaction Processes	• Public proposes that the private sector use the R&D results, and the private sector uses them and provides feedback to public.
B3	Interaction Outcome	• Public and private sectors collaborate directly and proactively without actively facilitating interaction.
T1	Type of Business	• It is a business idea that utilizes outer space (*1)
OUT1	Collaboration Results (Private Business Results)	• Private sector is starting/is in the beginning stages of a commercial business by utilizing the R&D achievements of public sector (*2).
OUT2	Collaboration Results (Public R&D results)	• Public acquires new R&D achievements and provides them to the private sector (*2)

(*1) If the above is not applicable, it is a ground business idea that utilizes space data, know-how, and knowledge.
(*2) Acceleration and streamlining of government R&D through collaboration, utilization of results as government, and setting next-generation technology challenges will be considered separately.

Space PPP (TYPE5) project have made sales through commercialization or have moved to the stage of making sales including the establishment of business company, etc. As mentioned above, out of the 31 cases to be analyzed, 24 cases were evaluated for business creation, and 7 cases were N/A. OUT2 is defined as “1” when the public, through its collaborative activities, has improved the Technology Readiness Level (TRL) of the technology, registered a patent or program, and proposed the results to the private sector as a value proposition. OUT1&2 is defined as “1” only when both OUT1 and OUT2 are set to “1”, and “0” otherwise.

The dataset, which began in March 2023 and was completed in December 2023, is presented as Table 5.

3.2. Analysis method: QCA

Using the data described above, we conduct a Qualitative Comparative Analysis (QCA) in the next section in order to understand the combination of factors that lead to the creation of outcomes. QCA is a method that uses set theory and Boolean algebra to infer the causal relationship between factors and outcomes surrounding each project [49]. In this study, it is assumed that there are not only interactions among variables, but also multiple causal paths leading to the outcomes of private sector business achieved/not achieved, public sector R&D outcomes achieved/not achieved, and both simultaneously achieved/not achieved.

The first reason for using QCA is that it is a method that enables the identification of combinations of conditions under which certain outcomes do or do not occur, thereby enabling the typification of causal patterns [50]. In each of the Space PPP TYPE5 collaborative projects, there is no uniformity in the method of creating individual technologies and businesses, the method of integrating public and private resources, and the practical approach taken by the business producers. Even if they are defined in the same way as terms, the meaning and weighting of operations may differ depending on the context. When dealing with such phenomena, assuming an "additive" causal relationship between a variable and an outcome may discard the diversity of causal pathways [51]. The second reason is to use data that are not suitable for either statistical analysis or simple case analysis [50]). In this study, a maximum of 31 cases were targeted for which data were accessible. On the other hand, the number of Japanese space PPP collaboration cases remains small, and it is difficult to further increase the number of targeted cases. However, it is also difficult to perform intuitive case comparison with the number of 31 cases. When dealing with such a medium-size sample, QCA is a suitable method for studies that conduct causal considerations while ensuring transparency [52].

Based on the above, analysis by QCA is performed as a highly effective method for the purpose of this paper.

4. Analysis

4.1. QCA procedures and results

It is said that the number of conditional variables to be included in the analytical model should be the minimum necessary [50]. In this paper, since the number of variables has already been narrowed down to 8 in Table 4 and is considered to be set to the minimum necessary, QCA was performed on all of these variables. In order to ensure the robustness of the results, all thresholds were set to exceed the recommended values by Dusa [53], and the thresholds for the necessary condition analysis were inclN$\geq$0.90, relatedness RoN$\geq$0.60, and coverage covN$\geq$0.60. The tilde (~) in front of the variable name is a symbol meaning negation. The actual environment used was R 4.3.1 (2023-06-16) and the package "QCA 3.20 (2023-7-13).

Following the general QCA protocol, we first examined the existence of the necessary conditions for the creation of business outcomes for the private sector and R&D outcomes for the public sector. According to the output results, the acquisition of private-sector business outcomes requires “Sense opportunity (A1)”, “Mutual Capacity/Benefit Estimation for Public (A21)”, “Mutual Capacity/Benefit Estimation for private (A22)”, and “Interaction outcomes (B3)”; the acquisition of public-sector R&D outcomes requires “Sense opportunity (A1)”,”Set collaboration goal setting and commitment (A3)”,” interaction management (B1)”, “interaction process (B2)”, and “interaction outcome (B3)”.

Next, based on the truth table in Table 6, the logic equations for the sufficient conditions that lead to the achievement acquisition/unacquisition of private business and public R&D outcomes were derived as the solution of QCA by simplifying them using the Quine-McCluskey

Table 5
Dataset.

CASE	Business	Tech	OUT1	OUT2	OUT1&2	A1	A2-1	A2-2	A3	B1	B2	B3	T1
1	NA	✓	NA	1	NA	1	0	1	1	1	1	1	1
2	NA	✓	NA	1	NA	1	0	0	1	1	1	1	1
3	NA	✓	NA	1	NA	1	0	0	1	1	1	1	1
4	NA	✓	NA	0	NA	1	0	0	0	1	1	1	1
5	✓	✓	1	1	1	1	1	1	1	1	1	1	1
7	✓	✓	0	1	0	1	1	0	1	1	1	1	1
9	✓	✓	0	0	0	1	0	0	0	1	1	0	1
10	✓	✓	1	1	1	1	1	1	1	1	1	1	1
12	✓	✓	1	1	1	1	1	1	1	1	1	1	1
13	✓	✓	1	0	0	1	1	1	0	1	1	1	1
14	✓	✓	1	0	0	1	1	1	0	1	1	1	1
15	✓	✓	1	0	0	1	1	1	0	1	1	1	0
16	✓	✓	0	0	0	0	0	0	0	1	0	0	1
17	NA	✓	NA	1	NA	1	1	1	1	1	1	1	1
21	✓	✓	1	0	0	1	1	1	0	1	1	1	1
23	NA	✓	NA	1	NA	1	1	1	1	1	1	0	1
26	✓	✓	1	1	1	1	1	1	1	1	1	1	1
27	✓	✓	0	1	0	1	0	1	1	1	1	1	0
28	✓	✓	0	1	0	1	0	0	1	1	1	1	1
29	✓	✓	0	1	0	1	0	1	1	1	1	1	1
30	NA	✓	NA	1	NA	1	0	1	1	1	1	1	1
31	✓	✓	1	1	1	1	1	1	1	1	1	1	1
32	✓	✓	1	0	0	1	1	1	0	1	1	1	0
33	✓	✓	1	1	1	1	1	1	1	1	1	1	0
34	✓	✓	1	0	0	1	1	1	0	1	1	1	0
35	✓	✓	0	1	0	1	0	1	0	1	1	0	0
36	✓	✓	1	1	1	1	1	1	1	1	1	1	0
37	✓	✓	1	1	1	1	1	1	1	1	1	1	0
40	✓	✓	0	0	0	1	0	1	0	1	0	0	0
41	✓	✓	1	1	1	1	1	1	1	1	1	1	0
46	✓	✓	0	0	0	1	1	1	0	1	1	0	0

Note 1) In the QCA, analysis and evaluation are conducted separately for the status of business creation and the status of R&D results creation by this PPP. Cases to be covered are indicated by ✓, and cases to be excluded from coverage are indicated by NA, respectively. There are seven cases in which the analysis/evaluation of the status of business creation is not conducted, while the analysis/evaluation of the status of R&D results creation is conducted. These seven cases are those in which the acquisition of R&D results was confirmed for each PPP project, but the status of business results acquisition cannot be determined at this time.

method. The Quine-McCluskey method is a computational rule that is standardly used in QCA to simplify logical expressions expressed as Boolean values [51,53]. The thresholds for the acquisition and unacquired conditions were set to 1.00 and 0.75, respectively, based on the consistency (incl) criterion.

Although QCA can derive three types of solutions: Complex Solution, Parsimonious Solution, and Intermediate Solution, this paper's interpretation is based on the Parsimonious Solution, given its exploratory nature [50]. The Parsimonious Solution is a means of eliminating redundant conditions in a reliable manner when logical residues exist. Note that the configuration of the arrangement that is inconsistent with the necessary conditions was not used in the process of deriving the Parsimonious Solution.

5. Consideration

Tables 7–1 and 7-2, and 7-3, in order, summarize the Parsimonious Solution obtained from QCA, divided into three categories: the analysis case from the private sector's business outcome creation perspective, the analysis case from the public sector's R&D outcome creation perspective, and the analysis case from the simultaneous creation of both. In the tables, "✓" means that the relevant condition is satisfied, and "x" means that the relevant condition is not satisfied. Blank conditions do not affect the results.

Table 7–1 through 7-3 are used to exteriorize the QCA solution in the vertical (column) direction. In the private business perspective, one combination of achievement conditions (BIZ-AD-1) and three combinations of non-achievement conditions (BIZ-NA-1, -2, and -3), totaling four causal pathways, are configured. From the public R&D's perspective, it consists of three combinations of achievement conditions (R&D-AD-1, -2, and -3) and four combinations of non-achievement conditions (R&D-NA-1, -2, -3, and -4), for a total of seven causal pathways. In addition, from the perspective of both private-sector business outcomes and public-sector R&D outcomes, it consists of one combination in which both are achieved simultaneously (BOTH-AD-1) and three combinations of conditions in which one of them is unachievable (BOTH-NA-1, -2, and -3).

This chapter interprets the characteristics of each path and the requirements for its formation.

5.1. Patterns of achievement/non-achievement and their factors from a private business perspective

According to the QCA solution, there is one factor (BIZ-AD-1) that has achieved business creation in the 15 cases. (1)The public technology required to solve technological issues to create a private-sector business is at the applied research stage or higher, and there is a prospect of its application to the business through existing or new R&D (A2-1); (2)The private sector can formulate a commercialization plan using this technology (A2-2); and (3)The business that promotes this collaboration is not actively promoted by the JAXA's business producer. The producer does not have to actively promote the collaboration, but the private sector, business developer and the public sector, researcher and/or engineer must be able to collaborate with each other directly and proactively (B3).

On the other hand, there are three factors that result in non-achievement of business creation (BIZ-NA-1, BIZ-NA-2, and BIZ-NA-3). The public R&D technology required to solve technological issues for private sector is not above the applied research stage, and the prospect of its utilization in business has not been obtained (~A2-1), or the private sector is unable to develop a commercialization plan utilizing this technology (~A2-2), or if collaboration between private business

Table 6
Truth table (Up: Business, Down: Tech).

	A1	A21	A22	A3	B1	B2	B3	T1	OUT	n	incl	PRI	cases
10	0	0	0	0	1	0	0	1	1	1	1.000	1.000	16
142	1	0	0	0	1	1	0	1	1	1	1.000	1.000	9
160	1	0	0	1	1	1	1	1	1	1	1.000	1.000	28
169	1	0	1	0	1	0	0	0	1	1	1.000	1.000	40
173	1	0	1	0	1	1	0	0	1	1	1.000	1.000	35
191	1	0	1	1	1	1	1	0	1	1	1.000	1.000	27
192	1	0	1	1	1	1	1	1	1	1	1.000	1.000	29
224	1	1	0	1	1	1	1	1	1	1	1.000	1.000	7
237	1	1	1	0	1	1	0	0	1	1	1.000	1.000	46
239	1	1	1	0	1	1	1	0	0	3	0.000	0.000	15,32,34
240	1	1	1	0	1	1	1	1	0	3	0.000	0.000	13,14,21
255	1	1	1	1	1	1	1	0	0	4	0.000	0.000	33,36,37,41
256	1	1	1	1	1	1	1	1	0	5	0.000	0.000	5,10,12,26,31
	A1	A21	A22	A3	B1	B2	B3	T1	OUT	n	incl	PRI	cases
160	1	0	0	1	1	1	1	1	1	3	1.000	1.000	2,3,28
173	1	0	1	0	1	1	0	0	1	1	1.000	1.000	35
191	1	0	1	1	1	1	1	0	1	1	1.000	1.000	27
192	1	0	1	1	1	1	1	1	1	3	1.000	1.000	1,29,30
224	1	1	0	1	1	1	1	1	1	1	1.000	1.000	7
254	1	1	1	1	1	1	0	1	1	1	1.000	1.000	23
255	1	1	1	1	1	1	1	0	1	4	1.000	1.000	33,36,37,41
256	1	1	1	1	1	1	1	1	1	6	1.000	1.000	5,10,12,17,26,31
10	0	0	0	0	1	0	0	1	0	1	0.000	0.000	16
142	1	0	0	0	1	1	0	1	0	1	0.000	0.000	9
144	1	0	0	0	1	1	1	1	0	1	0.000	0.000	4
169	1	0	1	0	1	0	0	0	0	1	0.000	0.000	40
237	1	1	1	0	1	1	0	0	0	1	0.000	0.000	46
239	1	1	1	0	1	1	1	0	0	3	0.000	0.000	15,32,34
240	1	1	1	0	1	1	1	1	0	3	0.000	0.000	13,14,21

OUT: output value.
n: number of cases in configuration.
incl: sufficiency inclusion score.
PRI: proportional reduction in inconsistency.

developers and public R&D researcher and/or engineer will not progress without the active promotion of collaboration by the business producer mediating this public-private partnership (∼B3), the possibility that the private sector will not be able to create a business will increase.

The above suggests that in the early stages of a public-private partnership project, it is extremely important to align the R&D plans of the public sector with the technical issues of the private sector. Then it's also important to fully estimate the feasibility of the project and the potential for upgrading and utilizing the public sector's technologies. Generally, in many cases, the public and private sectors do not have sufficient acquaintance and mutual understanding at the initial stage. Therefore, when the private sector asks the public sector to address technical issues (A1), JAXA's business producer gathers information on the private sector's business plans and technical issues, as well as JAXA's status and R&D plans for the relevant technology. Then, through dialogue, the two parties will attempt to harmonize their plans. Then, the capabilities of both parties will be estimated to confirm the feasibility of the private sector projects and the feasibility of JAXA R&D. For this reason, the leadership and intermediary function of the JAXA's business producer is extremely important in the initial phase. In some cases, the consistency of plans and the estimation of capabilities and profit were incomplete in the initial stage, and the business producer needed to review them as appropriate through dialogue. On the other hand, it was suggested that in realizing commercialization, it is important for the public and private sectors to become a direct and proactive collaboration even without the collaboration promotion function of the business producer, from the middle of the collaboration. At this stage, there will be cases where the private sector and the public sector will begin to efficiently obtain results that cannot be obtained by private-sector alone business development or public-sector alone R&D. In addition, by assuming the utilization of the results for private-sector projects, the priority of R&D by the public sector will increase, leading to the initiation and acceleration of R&D, as well as to an improved understanding of the results of R&D both within and outside the public sector. These were new motivations and commitments to participate in the collaboration. JAXA's business producers are expected to manage the PPP team in such a way that it becomes such a PPP team operation.

5.2. Patterns of achievement/non-achievement and their factors from a public R&D perspective

According to the QCA solution, there are three factors (R&D-AD-1, R&D-AD-2, and R&D-AD-3) that have achieved the creation of R&D outcomes by public sector. The 20 cases corresponded to the causal pathway R&D-AD-1 with a high degree of elementary coverage. The first factor is that both the public and private sectors set collaborative goals and commit to activities to achieve those goals (A3). If public-sector activities can be aligned with existing R&D plans, it will be possible to produce new technological R&D results with minimal additional resources, at the speed of the private sector. The public can also gain new perspectives from the private sector. In addition, by defining the activities of the public sector as independent of the commercialization activities of the private sector, it will also be possible for the public sector to promote R&D at its own discretion, even in the context of PPP collaboration. As a result, the technological achievements of the public sector are utilized in private sector projects. The second factor is to build a collaborative process (B2) based on the private sector's ability to develop commercialization plans (A2-2), even if the technological level of the public sector is not necessarily high (∼A2-1). The third factor is similar to the second factor in terms of ∼A2-1 and B2, but is different from the second factor in that a ground-based space businesses(∼T1) are not necessarily affected by private sector's ability to develop commercialization plans (A2-2). The second and third factors suggest that even when the public R&D base is not necessarily mature, it is possible to

Table 7-1
QCA solutions for business creation cases (savings solutions).

NO.	Variable	Private Business achievements			
		Achieved	Not Achieved		
		Biz-AD-1	Biz-NA-1	Biz-NA-2	Biz-NA-3
A1	Sense Opportunities				
A2-1	Mutual Capacity/ Benefit Estimation for Public	✓	×		
A2-2	Mutual Capacity/ Benefit Estimation for private	✓		×	
A3	Collaboration Goal setting and commitment				
B1	Interaction Management				
B2	Interaction Processes				
B3	Interaction Outcome	✓			×
T1	Type of Business				
inclS	Wlementary consistency of Sufficient condition	1.000	1.000	1.000	1.000
CovS	Elementary coverage of sufficient condition	1.000	0.778	0.444	0.556
inclS	Solution consistency	1.000	1.000	1.000	1.000
CovS	Solution coverage	1.000	1.000	1.000	1.000
Cases	Corresponding example	15,32,34; 13.14.21; 33,36,37,41; 5,10,12,26,31	16; 9;28; 40; 35; 27; 29	16; 9;28; 7	16; 9;40; 35; 46

accelerate R&D, acquire new R&D results, and propose them to the private sector by conducting R&D with an exit for use in private sector projects.

On the other hand, four factors (R&D-NA-1, R&D-NA-2, R&D-NA-3, and R&D-NA-4) were identified as contributing to the failure to generate R&D results: The first factor is the inability to propose public-sector technology results in a form that the private sector can easily use (~B2). The second factor is that the public R&D technology, which is the base of the project, is in the applied research stage (A2-1), but the commitment to collaborative activities is weak (~A3) due to the lack of a set of collaboration goals for both parties. The third factor is that both parties are still unable to reach a solution to the technological problem by utilizing public technology (~A2-2), and both parties are unable to set a goal for collaboration (~A3). The fourth factor is that in the case of space-based business creation (T1), the public R&D will be a large resource burden beyond the existing plan, making it difficult to set collaboration goals and commit to activities (~A3).

These results suggest that, from the public R&D perspective, in all cases, it is important for public officials to become aware of new ways to utilize public technology by understanding new private business ideas, as an opportunity to acquire new R&D results. Even in the case of collaboration based on technology that is not yet in the applied research stage, it was confirmed that aligning the private sector's technological issues with the public own technological development plan can lead to opportunities for the public to acquire new R&D results. It was confirmed even when the realization of a private sector project is difficult or needs more time. This finding suggests that expanding the application of public-sector R&D results to private-sector business development projects, in addition to the usual joint research approach, may promote the enhancement of new public-sector R&D capabilities. The importance of public R&D will increase as the public realizes new ways to use R&D results by responding to the needs and speed of the private sector. As a result, public resources are invested on a priority basis, resulting in the acceleration of R&D that should be the responsibility of the public. Conversely, if in the collaboration, the public is expected to play a role that deviates significantly from the public existing R&D activities, this will overload the public resources, raise doubts about the collaborative activities, and interrupt the collaboration. Therefore, at the initial stage of the collaboration, it is extremely important to evaluate the feasibility of A3 (Collaboration Goal setting and commitment) and the prospect of establishing B2 (interaction processes). In actual cases, even when the hurdles to commercialization are high, it was confirmed that through collaboration, the private sector can absorb the R&D knowledge and know-how of the public sector, leading

Table 7-2
QCA solutions for tech creation cases (savings solutions).

NO.	Variable	Public R&D achievements						
		Achieved			Not achieved			
		R&D-AD-1	R&D-AD-2	R&D-AD-3	R&D-NA-1	R&D-NA-2	R&D-NA-3	R&D-NA-4
A1	Sense Opportunities							
A2-1	Mutual Capacity/Benefit Estimation for Public		×	×		✓		
A2-2	Mutual Capacity/Benefit Estimation for private		✓				×	
A3	Collaboration Goal setting and commitment	✓				×	×	×
B1	Interaction Management							
B2	Interaction Processes		✓	✓	×			
B3	Interaction Outcome							
T1	Type of Business			×				✓
inclS	Wlementary consistency of Sufficient condition	1.000	1.000	1.000	1.000	1.000	1.000	1.000
CovS	Elementary coverage of sufficient condition	0.950	0.250	0.100	0.182	0.636	0.273	0.545
inclS	Solution consistency	1.000	1.000	1.000	1.000	1.000	1.000	1.000
CovS	Solution coverage	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Cases	Corresponding example	2,3,28; 27; 1,29,30; 7;23; 33,36,37,41; 5,10,12,17,26,31	35; 27; 1,29,30	35; 27	16; 40	46; 15,32,34; 13,14,21	16; 9;4	16; 9;4; 13,14,21

Table 7-3
QCA solutions for both business & tech creation cases (savings solutions).

NO.	Variable	Both (Private & Public achievements)			
		Achieved	Not achieved		
		Both-AD-1	Both-NA-1	Both-NA-2	Both-NA-3
A1	Sense Opportunities				
A2-1	Mutual Capacity/ Benefit Estimation for Public	✓	×		
A2-2	Mutual Capacity/ Benefit Estimation for private	✓		×	
A3	Collaboration Goal setting and commitment	✓			×
B1	Interaction Management				
B2	Interaction Processes				
B3	Interaction Outcome				
T1	Type of Business				
inclS	Wlementary consistency of Sufficient condition	1.000	1.000	1.000	1.000
CovS	Elementary coverage of sufficient condition	1.000	0.467	0.267	0.733
inclS	Solution consistency	1.000	1.000	1.000	1.000
CovS	Solution coverage	1.000	1.000	1.000	1.000
Cases	Corresponding example	33,36,47,41; 5,10,12,26,31	16; 9;28; 40; 35; 27; 29	16; 9;28; 7	16; 9;40; 35; 15,32,34; 13,14,21

to the promotion of commercialization by the private sector. These are the secondary results of this collaboration for the private sector.

5.3. *Patterns of achievement/non-achievement and their factors from a both (business & R&D) perspective*

According to the QCA solution, there is one factor (BOTH-AD-1), which has led to the creation of private sector business projects and the acquisition of new R&D achievements by the public sector and their proposal to the private sector, with nine cases applicable to this category. This causal pathway is as follows: the level of public R&D technology needed to solve technological problems for the creation of private-sector businesses must be at the applied research stage or higher, and there must be a prospect for its use in business, either already or through new R&D (A2-1); the private sector must be able to develop commercialization plans using this technology (A2-2); and both public and private sectors must set collaborative goals and commit to activities to achieve these goals (A3). On the other hand, three factors (BOTH-NA-1, BOTH-NA-2, and BOTH-NA-3) apply when any one of the above achievement factors fails to satisfy the criteria. If the public technology required to solve the technological issues for private-sector business creation is not at a level above the applied research stage, and the prospect of its utilization in business has not been obtained (~A2-1), or if the private sector is unable to develop a commercialization plan by utilizing this technology (~A2-2), or if both parties are unable to set a collaboration goal (~A3), the possibility that the private-sector business creation will not occur increases.

These results suggest that when aiming for the simultaneous realization of private-sector business and public-sector R&D results, it is important to align the public-sector R&D plan with the private-sector technology issues at the initial stage of collaboration, and to fully estimate the feasibility of the private-sector business creation, the acquisition of public-sector R&D results, and the possibility of utilizing these results. Furthermore, it is suggested that it is extremely important for both the public and private sectors to set and commit to the collaboration goals (A3).

The above results suggest that when the goal is only to create new private business, it does not necessarily require new R&D results from the public sector, and that it is more important to be proactive and active in public-private interaction (B3) than to set and commit to a collaborative goal (A3) from the results of the comparison between "BIZ-AD-1" and "BOTH-AD-1". This is because it includes cases where new businesses were created by focusing on how to use and apply existing R&D results from the public sector to private sector projects. However, this case is not originally included in the co-creation Type 5 of the Space PPP, but would fall into the Type 4 technical support type as organized by Kim [2,4]. In order to establish this Type 5 Space PPP and achieve both private business and public R&D outcomes, it is important to focus on the establishment of the collaboration goal setting and commitment (A3 factors) in the initial stage. It will then be necessary to develop the relationship into a direct and proactive interactional relationship.

6. Discussion

6.1. *New space PPP type compatible with the Japanese environment*

This paper presents a new type of Space PPP, the Co-Creation Type 5, which aims to simultaneously realize the acquisition of innovative R&D results by the public sector and the creation of space business by the private sector through mutual interactive cooperation. The combination of process factors that enhance the success was also identified by QCA using original data in Japan. By doing so, we aimed to address the issues that previous studies have pointed out, such as the relative reduction of R&D opportunities for the public sector due to the public focus on technological support for the private sector, and the decline in technological performance of the space commercial business due to the private sector's avoidance of technological risk. In Japan, where resources are scarce, we aimed to allocate resources appropriately, promote public R&D and challenging missions, and create private businesses at the same time. In conducting the QCA analysis, we divided the analysis into space and ground-based projects to take into account the differences in the degree of difficulty of creating commercial businesses that are often lumped together with the space industry.

It was suggested that in order to promote this Space PPP, it is extremely important for both the public and private sectors to have the capability to deal with the collaboration, to estimate the benefits to be gained from the collaboration (A2-1 and A2-2), and to set and commit to the collaboration goals (A3), which are included in the BOTH-AD-1 combination conditions. In the case of Japanese Space PPPs, it was confirmed that a JAXA's business producer was established from the initial stage of the partnership to take charge of this coordination and to promote dialogue and collaboration between the public and private sectors to realize the above factors. In the cases that subsequently produced private-sector commercial businesses, it was confirmed that as the collaboration progressed, the interactional relationship in the public-private collaboration matured to the point where there was no need for a business producer, and both the public and private sectors were proactively and actively promoting the collaboration. In this situation, it was confirmed that the public sector proposes to the private sector technological results that are easy to use in private sector commercialization, and the private sector uses those technological results and feeds back the results to the public sector.

On the other hand, OUT1 = 1&OUT2 = 1 is necessary to simultaneously create both public-sector technological achievements and private-sector business. A detailed analysis of the process factors shows that there were four cases (OUT1 = 1&OUT2 = 0) in which the creation of a private space industry was not necessarily combined with the combination of new technology acquisition. In these cases, the PPP was intended to be a co-creation type (Type 5), but as a result, it became a PPP similar to a technology support type (Type 4), and did not provide new R&D opportunities through the collaboration. It was suggested that A3 is important (R&D-AD-1) in order to launch and promote co-creation type Space- PPP (Type 5).

As suggested by the two factors (R&D-AD-2 and R&D-AD-3) for acquiring public-sector technological results, it was confirmed that even in the case of low public-sector technological maturity (~A2-1), the establishment of an appropriate interaction process between the public and private sectors (B2) would be a process factor that would enable technology acquisition through the use of this collaboration opportunity. This was a case where the public budget priorities on R&D were increased for the purpose of applying the technology to commercialization in the private sector, and as a result, the technology development progressed. In the future, it may be one measure to emphasize the establishment of this B2 factor in collaborations for the creation of larger, more challenging private-sector projects that require more time for business development.

Based on the comparison between "BIZ-AD-1" and "BOTH-AD-1", it was also confirmed that new private-sector business creation is possible without new public-sector technology development by establishing a proactive and direct collaborative relationship through appropriate capability/benefit estimation for both parties. The COTS program of NASA in the U.S. can be explained by this comparison and is considered to be a Type4 of Kim [2,4]. This will be an important issue when this collaboration is taken.

Findings based on the above results to enhance the success of this Type 5 collaboration are as follows.

1) Mutual capability estimation and goal setting between the public and private sectors are important in the initial stages of collaboration. However, they may be incomplete in the initial stage of collaboration and require review through mutual interactive interference.
2) Especially in the initial stage of collaboration, the facilitation function of interaction is important to align the expectations of both public and private sectors and to establish the collaboration. However, in order to obtain the results of the collaboration, it is necessary for both parties to change to direct interaction in accordance with progress.
3) By ensuring the public R&D autonomy and allowing the private to be creative in the use of the proposed value to bring out new value-in-use, collaboration is strengthened and the creation of results is accelerated.

6.2. Contributions and limitations

The first Finding of this paper is that a new type of collaboration in the space field is presented as a new co-creation type of Space PPP, Type 5, which simultaneously realizes the acquisition of innovative R&D results and mission promotion by the public and the creation of space business by the private sector through mutual interactive cooperation. The above findings can be considered as a contribution to the realization of open innovation-type collaboration between public R&D agencies and private companies. In addition, public R&D agencies, which have traditionally been in charge of R&D and national projects, will see the promotion of collaboration with private companies as an opportunity for new R&D and social implementation of the results, aiming to change conventional practices and encourage new initiatives for the creation of new industries.

The second Finding of this paper is that a combination of process factors that enhance the success of each project of this Space PPP was identified by QCA using original data in Japan. In conducting the analysis, a new set of indicators for evaluating collaboration in this PPP was established based on the results of previous research on value co-creation. This proposed measures to address the issues pointed out by previous studies, such as the relative reduction of technological research opportunities for the public as the public focuses on providing technological support to the private sector, and the decline in technological performance of the space business as the private sector avoids technological risks by increasing the burden of responsibility on the private sector. In particular, we believe that in a country like Japan, where resources are scarce, a new method of collaboration that simultaneously realizes R&D and mission promotion by the public and business creation by the private sector through the appropriate allocation of management resources could be a useful reference for future public policy considerations.

The discovery of the above two points and the presentation of the evaluation method for them are the academic contributions of this paper. The findings suggest that a co-creation Type 5 setting is appropriate as a new Space PPP that complements the Space PPP Typology organized mainly based on the U.S. case study, and that it can work through appropriate management of collaboration.

Finally, we discuss the limitations of this paper. First, this paper focuses on Japan's PPP practices in the space industry in comparison with the U.S. and Europe, but does not consider and analyze the situations of other space-faring nations such as India, China, etc. because not enough information has been provided yet. Second, it should be noted that the sources of the analyzed data are based on the network derived from the first author's work experience. While this allowed us to obtain data on about 30 cases at the level of each cooperative project, the cases taken up in this paper are limited to those in the creation of the Japanese space industry, the sample size is small, and the characteristics of space projects are divided into only two types: on-orbit projects and ground-based projects. In addition, third, the analysis dealt only with binary variables, which may have exaggerated certain characteristics. Therefore, we plan to further add to the analysis and supplement it with a detailed analysis of each PPP project.

CRediT authorship contribution statement

Shinichi Takata: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Kazuyoshi Hidaka:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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