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System Dynamics Modelling of Innovation Ecosystem with Two Cases of Space Instruments

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***Abstract*— To improve their competitiveness, many countries focus on innovation in the high-tech industry. This paper develops a system dynamics model for innovation ecosystems. The model emphasizes the interactions between high-tech innovations, the government, and universities. We use two high-tech instruments, the Mars Rock Corer and the Soil Preparation System, in the aerospace innovations developed by Hong Kong Polytechnic University. These instruments are a byproduct of collaborations with the European Space Agency, Russian Space Agency, and China Space Agency. They span decades of space missions to the moon and Mars. Here, we proposed a three parities systems dynamics model to study innovation behaviors. This model can be used to study and analyze the stakeholders' interactions in high technology-oriented innovation ecosystems. Theoretical, computational, and simulation studies were also conducted to understand and evaluate the evolution of the ecosystem. The results demonstrated the feasibility and effectiveness of this approach, which can be applied in on a large scale and in complex space projects.**

***Index Terms*—system dynamics modeling, innovation ecosystem, innovation collaboration, space instruments.**

I. Introduction

As science and technology have rapidly developed, innovation has become a powerhouse for gross domestic product growth in almost all industries [1][2]. Innovations in product development, technology, engineering, advertising, promotion, and blockchains are often seen in the manufacturing and services industries [3][4]. Projects and research that focus on the innovation of a single company, product, or technology are common [9][10]. In the open innovation approach, however, innovations are shared across companies and industries. Open innovation has the broadest range of applications and social network structure. This range is due to the diversity of participants, including innovators, the user's community, and supply chains [5]. The open innovation paradigm is widely used for both business and scientific purposes to generate additional value [6].

In the past few decades, scholars have discussed the concepts of openness, distribution, and decentralization of innovation [7]. These three properties help innovators generate creativity and exceed the boundaries of a simple internal environment. They are now becoming linked to a more complex *innovation ecosystem*. This ecosystem includes new participants and institutional entities whose functional goal is to enable technological development and innovation [8].

The ecosystem term originated from biological ecosystems. The innovation ecosystem refers to a comprehensive system that connects people, enterprises, communities, institutions, governments, and the environment around them. Like a biological ecosystem, the innovation ecosystem allows these components to function together as a unit [11]. The innovation ecosystem can be divided into two principal components: knowledge (scientific and academic) and commercial (driven by the marketplace). The relationship between these two sides is close and complicated. Resources invested in the knowledge economy are often derived from the commercial sector (e.g., government investment, R&D investment) [12]. The ecosystem is even more complicated for high-tech industries such as the space and aviation industry, with the government and universities having a more prominent influence. Studying the evolutionary dynamics of the innovation ecosystem can guide future innovation, especially in the space and aviation industry.

This paper describes a general model of the dynamics of innovation ecosystems from a theoretical perspective. The model emphasizes the interaction between government, universities, and the community in terms of high-tech innovation. Two high-tech instruments in the aerospace innovation area that were developed by the Hong Kong Polytechnic University (PolyU) include the Mars Rock Corer and the Soil Preparation System (SOPSYS). These instruments are used in the model as case studies of participants' interactions within a technology-oriented innovation ecosystem. Based on the system dynamics (SD) model of innovation, macro- and micro-system dynamics diagrams depict how the participants and their actions shape the dynamics of the ecosystem.

Over the last few decades, PolyU has worked closely with several governments and institutions on various space missions. These missions are typically deep space explorations and involve the design and development of high-tech technologies. A collaborative ecosystem was first formed with the development of a Holinser forceps system for space. The instrument was inspired by a pair of dental forceps in 1989. It was developed by a team of scientists from the Department of Industrial and Systems Engineering at PolyU led by professor Kai Leung Yung. It was successfully installed and commissioned in 1994 and delivered to the former Mir space station for astronauts to use in precision soldering.

As a result of successful innovation on the forceps system, the PolyU project team was invited by the European Space Agency

(ESA) to bid on its Mars Express Mission in 1994. The goal was to design and manufacture a space sampling tool for the Mars Express mission in 2003. After several years of research and development, the PolyU research team invented the Mars Rock Corer. The Mars Rock Corer was a multi-functional sampling instrument designed and manufactured by PolyU as early as 2000. The ESA commissioned the PolyU team. The prototype of the Mars Rock Corer was sent to the ESA for further testing and development. Subsequently, the corer was installed on the Beagle 2 lander and sent to Mars as part of the ESA's Mars Express Mission in 2003. The innovation of this space instrument gained attention form the community and government. PolyU received several awards and formed a sound foundation for future cooperation between the university, governments, and related institutions in space exploration technology.

After further work in space instrument development, PolyU joined the China National Space Administration (CNSA). Joining CNSA instigated a long-term relationship with the CNSA's Lunar Exploration Program Centre. PolyU contributed to training and scientific research from 2006 onwards. The work represented an official collaboration between the government, university, and scientific community. Following the official announcement of the partnership and supports from the CNSA and the Chinese government, the innovation ecosystem began to emerge.

The next project, the SOPSYS instrument, was part of a collaboration agreement signed by the Chinese and Russian governments. SOPSYS was designed for a mission to Mars to collect soil samples from its innermost moon, Phobos. As with previous tasks, PolyU designed and manufactured the device. PolyU also designed and manufactured many other space instruments that were used in the national space missions. For example, PolyU entered into an agreement with the China Academy of Space Technology (CAST) in 2010. This work will include research and development in Chang'e, China's lunar exploration programs.

Given the experience of PolyU, this paper explores the factors that influence innovation ecosystems in the high-tech industry. Space innovation projects take years or decades, considerable investments, and enormous resources. They draw talent from universities, the government, and the community. Constructing the innovation ecosystem requires the design and development of new materials, complex processes, and thousands of tasks. To foster the innovation process or initiate innovation, governments and public policies must recognize and facilitate entrepreneurship within multiple local contexts [13]. Moreover, a nation's competitiveness is reflected by its innovation and its advances in space exploration. It is, therefore, crucial to construct a well-developed, evolving innovation ecosystem - as well as the incentives for the involved participants (governments, universities, and communities).

The purpose of this paper is to: **a) understand the different stakeholders' perspectives in the innovation process; and b) comprehensively describe the innovation ecosystem of the high-tech space industry**. Using two case studies, we focus on two questions:

Q1: How do governments, universities, and high-tech enterprises involve themselves in the innovation ecosystem and support innovations?

Q2: Are the relationships and interactions between the space innovation participants the same as those of open innovation in the business community?

Our analysis yields several insights that can guide high-tech industries to make more efficient innovation ecosystems. A high-tech innovation ecosystem faces risks, including political and economic changes, brain drain, and skilled-labor shortages. To mitigate these risks, an innovation collaboration that includes high-tech enterprises, the government, and the university's research project team is crucial. Such a collaboration can help the innovation process to resume normal activity easily and quickly. Using SD, our work reveals the relationships among the high-tech enterprises, the government, and the research project team within the innovation ecosystem.

Further, we show various factors and their relationships within the ecosystem, including the abilities of refinement (ARef), design and development (AD&D), innovation (AIn), and redesign and improvement (ARdI).

The paper is organized as follows. Section II presents the literature review. Section III describes the two case studies and provides SD diagrams at the macro- and micro-level for analysis. Section IV presents the simulation results to address the primary two questions. Section V and VI include the discussion, recommendations, and conclusions.

II. LITERATURE REVIEW

This article is part of the growing literature on the innovation ecosystem, SD, and the high-tech industry.

A. Innovation Ecosystem

There is a large body of research on the dynamics of innovation ecosystems. This work is a combination of ecosystem dynamics with the high-tech industry.

1) Ecosystem Dynamics: Beliaeva et al. [14] investigated the dynamics of digital entrepreneurship. The work applied a multilevel perspective to examined the shaping of the innovation ecosystem. They examined the development of the company from lower to higher levels of digitalization. The results indicated that significant differences existed in the innovation ecosystem's actors and relationships. In a case study, the dynamic capabilities of the case company also played a crucial role in its innovation ecosystem [15]. Davis analyzed the group dynamics of interorganizational relationships in innovation ecosystems.

This work explored how groups of organizations innovated collaboratively. They moved beyond dyads to multi-partner innovation efforts as group dynamics evolved [16].

2) Ecosystems in High-Tech: Others have focused on innovation ecosystems in high-tech industries. A science, technology, and innovation ecosystem model showed that Germany is governed by the federal government and 16 federal states in high-tech industries [17]. He et al. [18] also constructed a classified evaluation of the innovation ecosystem cooperativity of regional high-tech industries based on the innovation ecosystem theory, the Lotka-Volterra model, and cluster analysis. Further, Beltagui et al. [19] outlined the implications for supporting new digital innovation ecosystems and cultivating exaptation opportunities for high-tech industries.

3) Ecosystem Dynamics in High-Tech: Few studies have examined the innovation ecosystem dynamics in the high-tech industry. Recently, Pekkarinen et al. [20] considered the dynamics of the emerging care robotics innovation ecosystem in Finnish welfare services. The results showed that a variety of stakeholders are needed in the ecosystem. However, the four important abilities of the ecosystem (discussed in Section IIIA and Fig. 3) are not analyzed in their work. Our analysis further analyses these abilities for the high-tech industries in an innovation ecosystem.

4) Gaps in the Literature: Previous work indicated the importance of the innovation ecosystem for the development of enterprises and even industries. Integrated knowledge and resources can generate even more value than participants can create separately. Participants from different fields can generate unexpected value by connecting and cooperating within the innovation process. The distribution of resources and knowledge allows for the flow of innovative ideas between universities, firms, communities, users, and governments. These entities may then operate together as a comprehensive innovation ecosystem. However, previous work did not consider the various factors and their relationships with high-tech industries in an innovation ecosystem.

B. System Dynamics (SD)

1) Method Design of SD: Malczyk and Frączek proposed a new parallel algorithm to simulate dynamics in general multibody systems [21]. Nunes et al. applied a dimensionless simplified mathematical model of a vapor compression refrigeration system to optimize the SD response [22]. Further, Rad and Rowzan proposed a hybrid SD model plan. This plan controlled the progress of a project portfolio while maximizing strategic adaptations subject to changes in human resources [23].

2) Application of SD to Practical Problems: Fan and Ding introduced a frequency-adaptive methodology in power SD studies to solve the slow simulation speeds of the Electromagnetic Transients Program [24]. Further, Jiang et al. [25] adopted SD to analyze the stability of the three-parties evolutionary game model for the online group-buying market. They obtained effective regulation strategies that can promote the healthy development of the group-buying market.

3) Application of SD to Sustainable Development: Bach et al. showed that SD modeling has a wide range of applications in urban sustainability [26]. Li et al. forecasted the sustainable development of green space in Beijing based on real-world policies [27]. The historical development of sustainable green space increased to its highest level in 2012 but declined slightly by 2015. Santiago-García et al. developed a dynamic growth and yield timber system for sustainable forest management [28]. Barati, Azadi, and Scheffran develop a smart groundwater governance model. This model assisted policy and decision-makers to understand the short and long-term impacts of their actions, plans, and policies [29]. The study determined the best strategy to address the situation and to govern groundwater resources more intelligently. Thirupathi, Vinodh, and Dhanasekaran built a suitable SD model to identify areas required for sustainable improvement in an automotive component manufacturing organization [30].

4) Gaps in the Literature: There has been little work on the use of SD to study the innovation ecosystem.

C. High-Tech Industry

1) Technology Transfer [31][32]: Some projects have described technology transfer networks as interorganizational innovation systems. This perspective arises from the practice of internal innovation generation with residual control of organizational resources [33]. For most of American history, professional knowledge was generated by universities [34]. High-tech instruments and technologies, on the other hand, were separate. For example, aerospace science and technology were controlled by the National Aeronautics and Space Administration (NASA).

2) International Collaborations: Swed and Butler described the accumulation of military capital during military service. As veterans, these former soldiers become employees in the high-tech sector [35]. Hu discussed the influence of international trade on the innovation capacity of the Chinese high-tech industry. They showed that international trade had a positive effect on technological innovation capacity. The influence of imports was stronger than that of exports [36].

3 Improving Labor Performance: He and Fallah investigated 15 high-performing metropolitan-based clusters in the United States. They concluded that the real-world clusters rarely featured any single typology; a mixed typology was much more prevalent [37]. Wu et al. showed that an eight-week outdoor brisk walking program significantly improved fatigue among employees of the high-tech industry [38].

4) Gaps in the Literature: Few studies have analyzed the innovation ecosystem in the high-tech industry by SD. Further, the relationships between governments, universities, and high-tech enterprises in the innovation ecosystem need to be analyzed.

D. Addressing Gaps in the Literature:

This paper bridges the three streams of research discussed in this section, the innovation ecosystem, SD, and the high-tech industry. We show various factors and their relationships with the important abilities of the ecosystem. Moreover, this work proposes strategies to improve the effectiveness of the innovation ecosystem.

Our work differs from previous studies in that we take stakeholders, their resources, and the flow of knowledge into account. We do so while focusing on the innovation ecosystem of the high-tech industry. Further, we analyze the dynamics of the four essential abilities for the innovation ecosystem. Finally, we provide suggestions for the development of the high-tech innovation ecosystem.

III. Innovation Ecosystem Modeling with System Dynamics

We have described the many parties and their roles related to the high-tech space industry within an innovation ecosystem [39][40]. These individual events interact with each other as a series of decisions and consequences [41]. Innovators should conceive of these individual decisions and their interactions as a coherent system. In doing so, innovators can get a better understanding of the mechanisms and dynamics of the innovation ecosystem, from micro- to macro-levels.

SD is a simulation modeling method based on the feedback control theory. The SD approach is suitable for studying complex problems are systems, such as sustainable development over extended periods. It has been used for analysis, decision-making, and policy formation in several applications and systems (e.g., industrial, healthcare-related, environmental, and demographic).

SD is also commonly used to analyze business and innovation ecosystems. It reveals ecosystem structure and graphs relationships and interactions within the ecosystem. Due to the complexity and the diversity of the innovation ecosystem, the SD model can be used to examine relationships and synergistic actions within the innovation ecosystem. The SD research framework for this paper shown in Fig. 1.

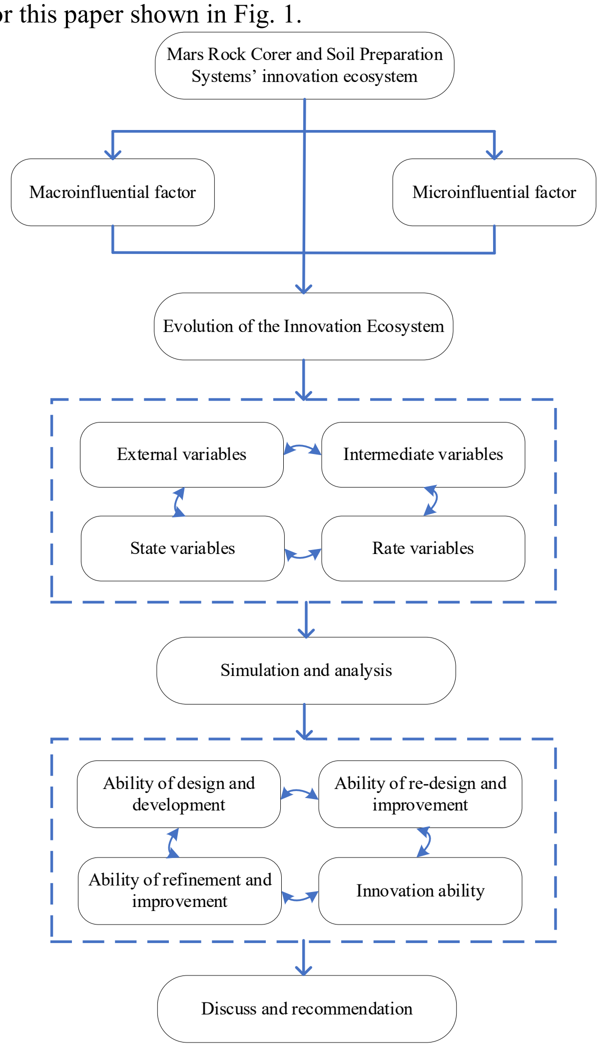

Fig. 1. Research framework.

A. SD Ecosystem: Models of Two Space Instruments

In this section, we analyze the innovation ecosystem using SD diagrams at the macro and micro levels.

1) Macro-Level: We use the innovation flow of product development using the space instruments' development process. This process includes concept development, system-level design, detail design, testing and refinement, and production [42]. This general product development model summarizes the process from the birth of an innovative idea that can satisfy a user's needs to the final implementation of the innovation product [43]. A representation of the macro-level SD of the innovation ecosystem is shown in Fig. 2.

In Phase 1, user requirements, the innovators in the forceps case study were a scientist and dentist. They observed the opportunity to develop space instruments for space agencies. The requirements of the products that could be satisfied through proper innovation and technological development.

Phase 2 is functionality development. Innovators develop an innovative idea using resources and technology. The idea is transformed to fulfill the space agency's requirements and needed functions.

Phase 3 is attribute development. Details like the features and shape of the product are developed through technical and physical design. The technology is optimized, and resources transformed.

In Phase 4, prototyping, the prototype of the product is manufactured and tested. By identifying the scope for improvement, the prototype is redesigned and refined to satisfy the needs of the space agency's missions.

In Phase 5, the final product, the product procedures through final testing. It is ready for launch after the optimization of parameters, which is the final adjustment.

In Phase (6), implementation, the innovative product is launched with space missions. The users' feedback and the subsequent reviews of the instruments provide innovative concepts for the development of the next generation.

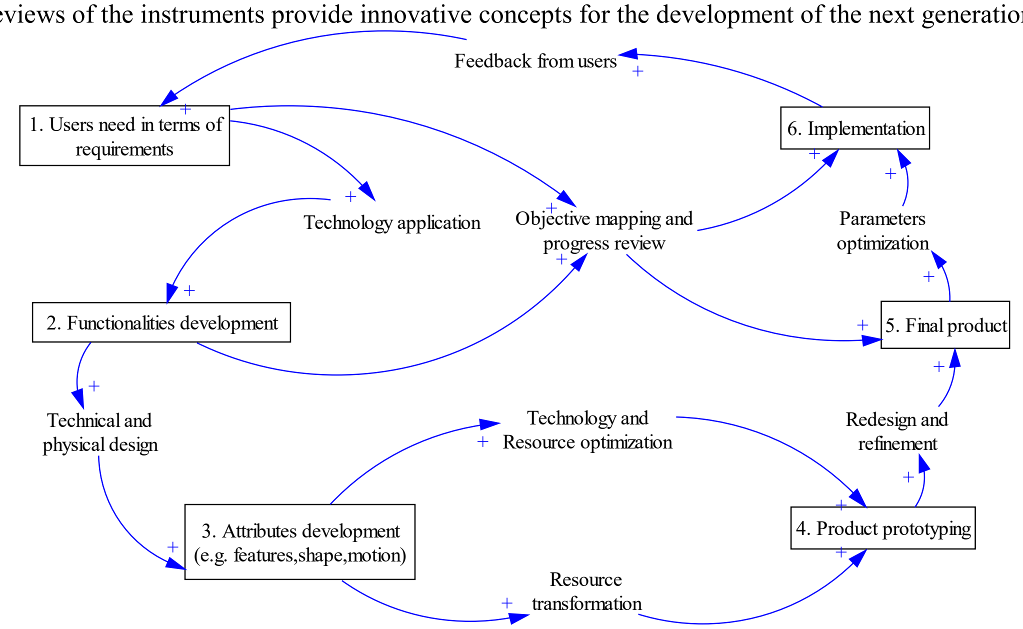

Fig. 2. The macro-level of the innovation ecosystem

2) Micro-Level: There are risks in the innovation ecosystem for any project. Thus, in our SD diagram (Fig. 3), we examine the resilience of four key abilities to risk. Te

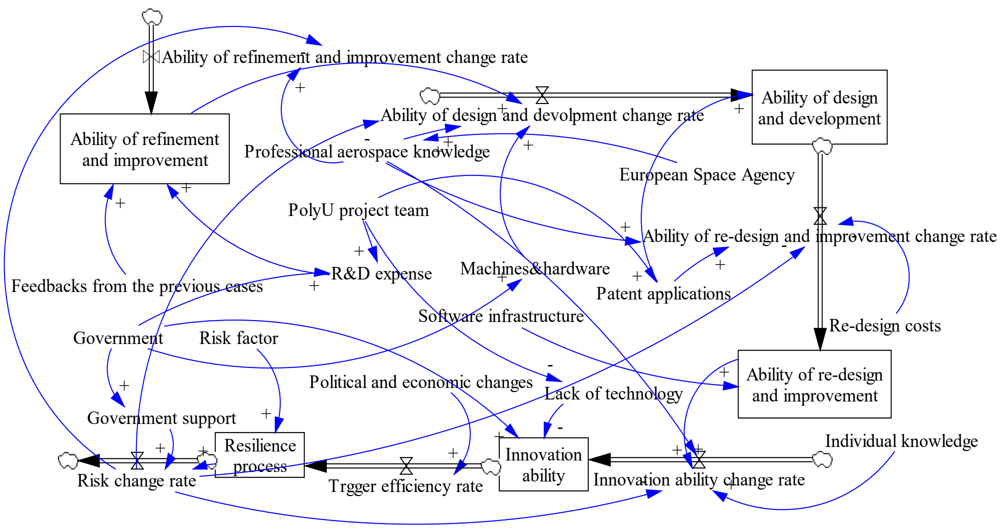

Fig. 3. The micro-level of the innovation ecosystem.

B. Evolution of the Innovation Ecosystem

A sustainable science and innovation ecosystem is made up of numerous complementary and diversified elements [44]. The development of the project and the ecosystem are a joint effort between the participants and the ecosystem itself.

During the Mars Rock Corer innovation process, participants from the government, space agency, and university created value. They integrated their own knowledge and resources to ensure the success of the larger project. The project garnered attention from around the world. It also attracted a broader group of potential collaborators from the Russian Space Agency, the ESA, and the CNSA. It grew from a small group of innovators to hundreds around the world.

SOPSYS was the next national aerospace project after the Mars Rock Corer. The development of the SOPSYS innovation ecosystem was pioneering. As with the innovation ecosystem of the corer, three overlapping stakeholders shared the credit for fostering the innovation. The innovation of these space instruments led to further collaboration between PolyU and the government in space instrumentation and space-used materials. The Phobos-Grunt mission eventually failed and crashed back to Earth in 2012. The innovative concept and the successful development of the SOPSYS, however, are irreplaceable and contribute to efforts for the future.

For our analyses, we assume a general dynamic of innovation ecosystem growth with overshoots and exponential growth models. The basic model is shown in the following two figures (Fig. 4 and Fig. 5).

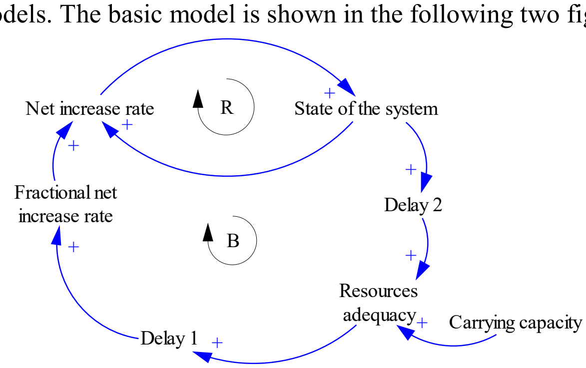

Fig. 4. Growth with overshoots.

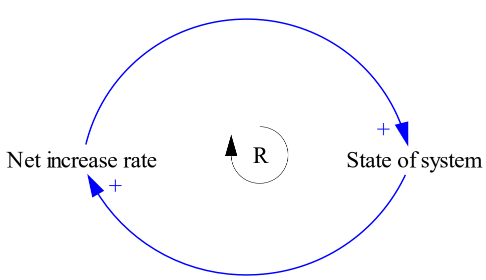

Fig. 5. Exponential growth.

IV. SIMULATION AND ANALYSIS

We used SD to study the relationships and interactions between participants in the innovation ecosystem [46]. Based on the above analysis, we considered the three stakeholders (Section IIIA and Fig. 3).

The model parameters are: simulation period is 12 months; INITIALTIME=0; FINAL TIME=12; TIME STEP=0.25. The model consists of nine external variables, six intermediate variables, five state variables, and six rate variables. Arrows indicate the correlation between variables. The variables are shown in Table 1.

TABLE 1
THE INITIAL VALUES OF VARIABLES IN SD MODEL

Variable type	Variable name	Equation
External	Individual knowledge	Individual knowledge level ϵ[0,1] (0: individual knowledge low; 1: individual knowledge high)
	Feedback from previous cases	Feedback efficiency level ϵ[0,1], (1-4: feedbacks efficiency low; 1 feedbacks efficiency high)
	PolyU project team	Provides R&D expense, technology support, and patent applications
	Local government	Provides government support, machine & hardware construction, R&D expense, and promotes innovation ability
	European Space Agency (ESA)	Provides aerospace knowledge
	Risk factor	2
	Redesign costs	0.4
	Software infrastructure	0.35
	Political and economic changes	0.3
Intermediate	R&D expense	(1/4)* government support+(1/4)* PolyU project team support
	Machines&hardware	(1/4)* government support
	Aerospace knowledge	From ESA
	Patent applications	(1/4)* PolyU project team support
	Government support	(1/4)* government support
	Lack of technology	0.6-0.01* PolyU project team support
State	ARef (Refinement & improvement ability)	ARef change rate* feedback from previous cases *R&D expense
	AD&D (Design and development ability)	AD&D change rate* patent applications
	ARdl (Redesign and improvement ability)	ARdI change rate* software infrastructure
	Ain (Innovation ability)	1- lack of technology+ AIn change rate+(1/4)* government support
	Resilience process	Trigger efficiency rate* risk factor
Rate	ARef and improvement change rate	(1-(1/2)* risk change rate)* (1/4)* aerospace knowledge
	AD&D change rate	Ability of refinement and improvement *machines&hardware* (1-(1/2)* risk change rate)* (1/4)* aerospace knowledge
	AIn change rate	ARdl* individual knowledge*(1-(1/2)* risk change rate)* (1/4)* aerospace knowledge
	ARdl change rate	(1- re-design costs)* patent applications *(1-(1/2)* risk change rate)* (1/4)* aerospace knowledge
	Trigger efficiency rate	(1/2)* political and economic changes
	Risk change rate	(1/3)* resilience process- (1/4)* government support

We set these values to sensitivity analysis. For simplified analysis, the simulation values do not represent the actual values.

For the SD model, dynamics diagrams describe how participants and their actions shape ecosystem dynamics. We first simulate the scenario without innovation collaboration. In this scenario, there is no government, and the PolyU project team support is a benchmark (S1). The simulation results of the four abilities are shown in Fig. 6.

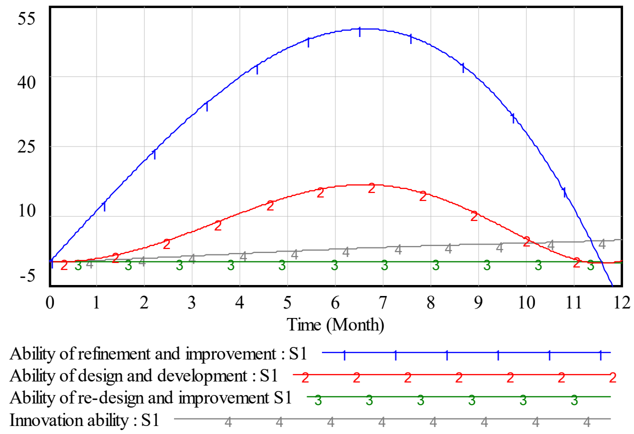

Fig. 6. The scenario without innovation collaboration. S1: PolyU support.

The four abilities can represent the development of the innovation system. As shown in Fig. 6, ARef and AD&D increase, then decrease. ARdI and AIn gradually increase over time. ARef peaked highest across the four kinds of abilities, followed by AD&D, AIn, and ARdI.

With the innovation ecosystem running, the high-tech innovation ecosystem faces risks. When there is no innovation collaboration (Fig. 6), ARef and the AD&D are affected by risks. Moreover, because of the risk, these two abilities eventually are reduced to zero. In this scenario, the innovation system is in a poor state. R&D expenses, the ESA, and spending on machines and hardware are useless without the innovation ecosystem and do not promote the development of innovation systems. The ARdI and AIn are less affected by risks; the resilience process can protect these two capabilities from risk.

We then simulated the scenario with the presence of innovation collaboration. Government and PolyU support are compared to no innovation collaboration: S1 (no innovation collaboration), S2 (government support), and S3 (PolyU support). The four abilities are shown in Figs. 7, 8, 9, and 10.

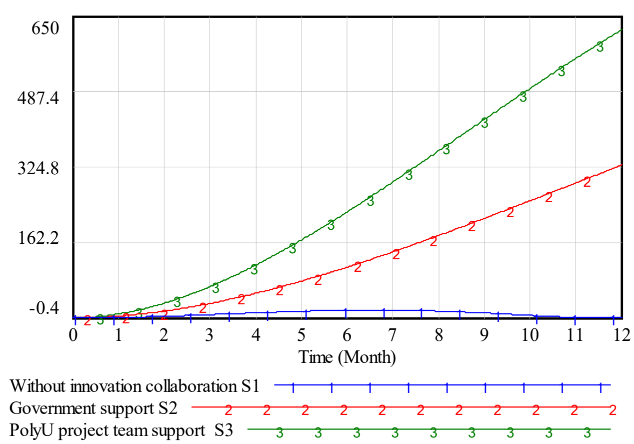

Fig. 7. The evolution of the ability of design and development (AD&D).

Compared to no innovation collaboration (S1), AD&D increases in a high-tech innovation ecosystem innovation with government support (S2) or PolyU support (S3). Moreover, AD&D is not affected by risk. The innovation ecosystem can, therefore, resist risk under innovation collaborations.

Next, we elaborate the reason for the results. PolyU project team and Government can provide some supports to accelerate the innovation from the most fundamental part. PolyU project team provides the R&D expense, technology support and patent applications. Government provides R&D expense, government support and machines & hardware construction. Furthermore, the development of ability of design and development needs some theoretical foundation, specialized knowledge and well-trained skills. Thus, PolyU project team and government can improve the ability of design and development in the innovation ecosystem of high-tech innovation.

Both the PolyU project team and government provide R&D expense. The different of them are technology support, patent applications and machines & hardware construction. Nonetheless, the PolyU project team have a much bigger influence to improve the ability of design and development. Thus, we can clearly know technology support and patent applications dominate machines & hardware construction to the enhancement of the ability of design and development.

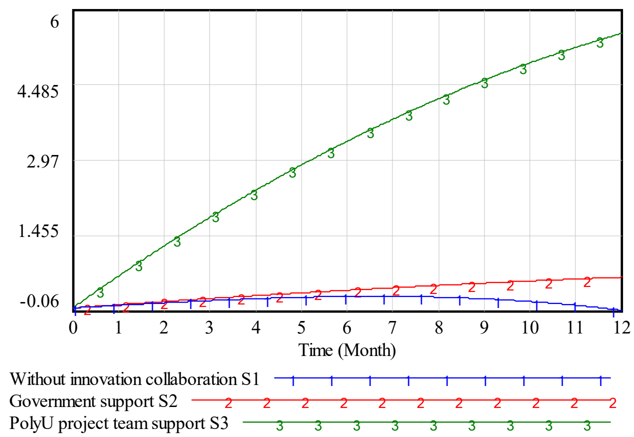

Fig. 8. The evolution of the redesign and improvement ability (ARdI).

Compared with no innovation collaboration (S1), ARdI increases with an innovation collaboration (Fig. 8). Moreover, the PolyU project team has a more considerable influence on improvements to ARdI.

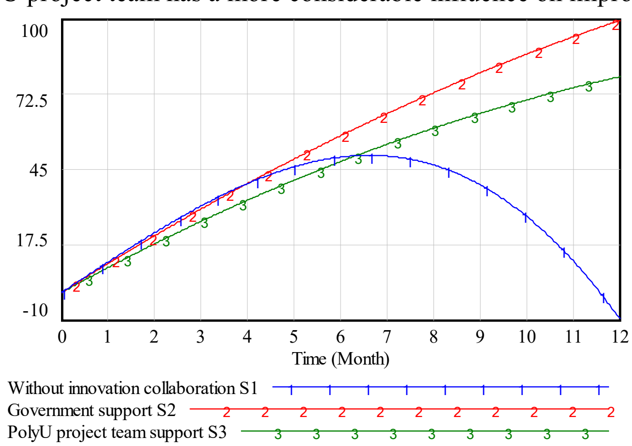

Fig. 9. The evolution of the ability of refinement and improvement (ARef).

Compared with no innovation collaboration (S1), ARef increases when the collaboration exists. Moreover, government support has a much larger influence on improvements to ARef (Fig. 9).

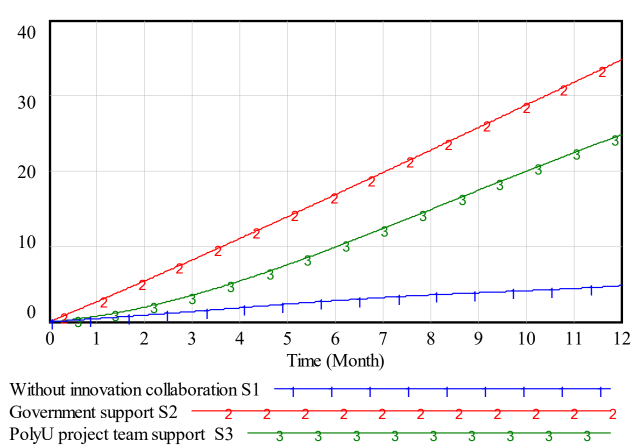

Fig. 10. The evolution of the innovation ability (AIn).

Compared with no innovation collaboration (S1), AIn increases when the innovation collaboration exists. Moreover, government support has a much larger influence on improvements to AIn.

V. Discussion and Recommendations

A. Principal Findings

In the innovation ecosystem, collaborations resisted risk. In SD models without the innovation collaboration, all four abilities were affected by risk. Further, the resilience process could not resist risk. Innovation collaborations develop resistance to risk disturbances that would otherwise cause failure. The collaborations help the innovation process to resume normal activity easily and quickly within an innovation ecosystem.

B. Impact of Support

Unlike business innovation ecosystems, PolyU support had a more substantial influence on improvements to AD&D in the high-tech innovation ecosystem. PolyU and the government can provide support that fundamentally accelerates innovation. Universities can provide R&D expenses, technology, and patent applications. The government can also provide R&D expenses, government support, and machine and hardware construction. Furthermore, the development of AD&D requires theoretical foundations, specialized knowledge, and training. Thus, support from PolyU and the government improved AD&D in our model.

Both PolyU and the government provided R&D expenses. The difference between them was technology support, patent applications, and machines and hardware construction. Nonetheless, PolyU had a larger influence on AD&D. Thus, technology support and patent applications are more important than machine and hardware construction for AD&D.

The reasons for the impact of support on ARdI and AIn are similar to AD&D. Technology support and patent applications are more important than government support and machines and hardware construction for ARdI.

In the innovation ecosystem, the innovation collaboration, including the European Space Agency, government support and the PolyU project team support are very important to resist the risk. Without the innovation collaboration, all four abilities will be affected by risks, and resilience process cannot well resist risks. Innovation collaboration is such a way as to continuously develop the resistance of the relevant process to risk disturbances that can be sources of major failures. The innovation collaboration helps the innovation process to resume its normal activity easily and quickly for an innovation ecosystem. Government support and the PolyU project team support also have different impacts on the four abilities. Thus, we should focus on different aspects to develop different capabilities in the innovation ecosystem. If fostering the AD&D or ARdI is a top priority, the research team should be given support for technology and patent applications. If the ARef and AIn are the top priority, however, the government should invest in machine and hardware construction.

VI. Conclusion

A thriving high technology-oriented innovation ecosystem can help the industry to exploit major projects, improve innovation, and develop advanced technology. This study developed an integrated framework to explore the innovation ecosystem. We demonstrated that the innovation process is an integrative and relevant process shared by multiple stakeholders.

There are three important contributions of our work. First, it provides a comprehensive analysis of the innovation ecosystem of the high-tech industries. We initially constructed the elements of the innovation ecosystem. We included stakeholders, their resources, and the flow of knowledge in the high-tech industry. We used the innovation process of two high-tech instruments, then examined the dynamics using SD. This paper develops the SD model from theoretical and practical perspectives. By formalizing the feedback dynamics with the SD model, this study constructed an evolving, well-developed innovation ecosystem.

The innovation processes, governments, universities, related institutions are considerably different across sectors. Therefore, future policy needs to focus on the cooperation among them, considering building the above four abilities to resist the risks.

We believe there are three important contributions of our work. First, it is a relatively comprehensive analysis for the innovation ecosystem of the hi-tech industries. Specially, we initially construct the elements of the innovation ecosystem including variety of stakeholders and their resources and knowledge flows in hi-tech industry by the analysis of the innovation process of two high-tech instruments including the Mars Rock Corer and Soil Preparation System, and then we examine the dynamic for an innovation ecosystem by using system dynamics. Second, we analyzed the four important abilities for high-tech industries in an innovation ecosystem. We introduced SD into the analysis of the innovation ecosystem of the high-tech industries. Through the analysis of the four important abilities, we obtained meaningful recommendations that clarified the incentives for all the stakeholders. The findings support the importance of strategic flexibility within governments, universities, and space agencies.

Finally, managerial insight was obtained. This can guide high-tech industries to make more efficient innovation ecosystems in the future.

Future research could occur in several directions. First, private companies can provide leading-edge technology, design, and practical experience. This also constitutes the technology optimization-and-product implementation layer of the innovation ecosystem. Thus, it is necessary to account for private companies in a dynamic system. Such a model of the innovation system would be more complex and interesting. Second, future research could consider the bounded rationality of governments, universities, and related institutions. It could test causality through experimental design to further explore the interaction of innovation systems.

Innovation collaborations help the innovation process to resume its normal activity easily and quickly in the face of risk. The innovation processes, governments, universities, related institutions are different across sectors. Therefore, future policy needs to focus on the cooperation among them and building the four primary abilities to resist risk.

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