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Evaluating the Collaborative Ecosystem for an Innovation-Driven Economy: A Systems Analysis and Case Study of Science Parks

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Abstract: National policies for science parks and innovation have been identified as one of the major driving forces for the innovation-driven economy, especially for publicly funded science parks. To investigate this collaborative ecosystem (government-academia-industry) for growth and sustainable development, this paper proposes a nation-wide economic impact analysis of science parks and innovation policy based on historical data drawn from one of the globally recognized high-technology industrial clusters in Taiwan. Systems thinking with causal loop analysis are adopted to improve our understanding of the collaborative ecosystem with science park policies. First, from a holistic viewpoint, the role of government in a science parks and innovation ecosystem is reviewed. A systems analysis of an innovation-driven economy with a science park policy is presented as a strategy map for policy implementers. Second, the added economic value and employment of the benchmarked science parks is evaluated from a long range perspective. Third, the concepts of government-academia-industry collaboration and policies to innovation ecosystem are introduced while addressing the measures and performance of innovation and applied R&D in the science parks. We conclude with a discussion of lessons learned and the policy implications of science park development and an innovation ecosystem.

Keywords: innovation; ecosystem; policy; sustainability; science park; systems thinking

1. Introduction

For decades, an innovation-driven economy has been promoted in different countries as the major driving force behind development and growth in the world. The success of science parks has motivated countries around the globe to foster the clustering of the high-tech industry into parks. The development of these science parks drive regional and economic growth, examples of which include Silicon Valley in the USA, Cambridge Science Park in the UK, in addition to parks found in Russia, Israel, India, Taiwan, Japan, Korea, and China. The science parks of Zhongguancun in Beijing, Daedeok Innopolis in Korea, and Hsinchu Science Park in Taiwan are globally recognized for their connection with public policy and governmental support. In addition, continuous innovation and ecosystem developments have been identified as the critical driving factors for industries to compete and thrive under highly intensive global competitions. Since science parks and innovation policy is generally adopted by government bodies, a nation-wide macro viewpoint is needed for policy evaluation and the ecosystem should be considered as essential component of the national/regional economy. The collaboration between government, academia, and industry require a systems perspective.

Recently, the issues of innovation and sustainability have become popular in academic thought. Several studies and public-private initiatives have highlighted the need to maintain and build capabilities to support economic growth, create job opportunities, and develop the nation by linking its capabilities to innovate with ecosystems. The concept of an innovation ecosystem is rooted in the literature on systems of innovation, building upon the endogenous growth theory that emerged in the 1980s [1] Previous studies show a greater appreciation of the connections among the many innovation actors. Enumerating the interactions among an ecosystem's component organizations highlights the richness and diversity of actors that can, in principle, give rise to emergent behavior [2]. Jackson [3] observes, "a dynamic innovation ecosystem is characterized by a continual realignment of synergistic relationships of people, knowledge, and resources that promote harmonious growth of the system in agile responsiveness to changing internal and external forces." Rao and Jimenez [4] present case studies of digital ecosystems at Apple Inc. (Cupertino, CA, USA) and Google (Mountain View, CA, USA), which are online platforms where customers, users, and developers build synergistic relationships, generating network externalities which increase the value of both hardware and software innovations. There are also new signs of city-based innovation ecosystems and innovation districts [5].

While the term "innovation ecosystem" can be used to refer to innovation systems within firms, districts or at a national level, the most common and perhaps most appropriate geography is the region (or for smaller countries, the country level) in which geographic proximity among actors is a key attribute of the ecosystem [6]. Thus, innovation ecosystems can be seen as inter-organizational, political, economic, environmental, and technological systems that are catalyzed, sustained, and supported. Furthermore, strengthening the regional innovation ecosystem as a whole will improve the "industrial commons" and leverage resources by helping all manufacturers in the country, not just the select few [7].

To investigate the government-academia-industry collaborative ecosystem for an innovation-driven economy, this paper proposes a nation-wide economic impact analysis of science parks and innovation policy based on historical data drawn from one of the globally recognized high-technology industrial clusters, the national science parks in Taiwan. Systems thinking with causal loop analysis are adopted to improve the understanding of the ecosystem and policies of the science parks. Taiwan's science parks have become globally recognized examples of science parks that are established for national prosperity. The policy of facilitating science parks and innovation has made a tremendous contribution to the development of high-technology industry clusters, the creation of innovation clusters, and the national economy. The promotion and development of high-technology industries by the government in the past two decades has been one of the most important factors driving economic growth. Science parks in Taiwan incubate six major industrial clusters, including the integrated circuits (IC) industry, the computer & peripherals industry, the telecommunication industry, the optoelectronics industry, the precision machinery industry, and the biotechnology industry. These science parks occupy merely 0.1% of the nation's total land area, but contribute around 16% to the nation's overall manufacturing revenue, 40% to its domestic IT industry, 14% to its foreign trade, and 15% of its domestic invention patent output. As key high-technology industry actuators, science parks act as a source of productivity growth and produce prosperity. Among the industrial clusters, several IT products and related industry capacities rank in the leading positions worldwide.

By adopting a case study methodology of science parks, this paper systematically evaluates the ecosystem of government-led science parks, the economic impact of science parks, and innovation policy with nationwide statistics. First, from a holistic viewpoint, the role of government in science parks and innovation ecosystem is reviewed. A systems analysis of the innovation-driven economy with science park policy is presented as a strategy map for policy implementers. Second, the added economic value and employment in the benchmarked science parks is evaluated from a long range perspective. Third, the concepts of government-academia-industry collaboration and policies to innovation ecosystem are introduced, while the measures and performance of innovation and applied

R&D in the science parks are addressed. Based on the research results, lessons learned and policy implications for science park development and innovation ecosystem are discussed.

2. The Role of Government in a Science Parks and Innovation Ecosystem

One of the major driving forces for the success of science parks in Taiwan are governmental organizations. As the government's dedicated scientific and technological development agency, the Ministry of Science and Technology (MOST) is tasked with three main missions, which include promoting the development of the nation's overall science and technology (S&T) sector, supporting academic research, and developing the science parks. In addition, the National Applied Research Laboratories (NARLabs) supports MOST's promotion of national S&T development through its vision of "global excellence, local impact." In the area of S&T policy, NARLabs is responsible for the following developments:

(1) Establishing mid-/long-term S&T trend monitoring and value-added intelligence analysis capabilities, performing S&T forecasting activities, planning and researching key issues, providing decision-makers with multifaceted analysis and intelligence on decision-making information.
(2) Establishing capable patent consulting teams and providing up-to-date specialized information.
(3) Assisting and supervising the country's innovation system operating environment, providing performance assessment and recommendations for the country's major programs, and improving S&T policy governance and the competitiveness of domestic innovation.

With the support of MOST and the NARLabs think tank, policies for science park development and innovation are consistently promoted in Taiwan, including the development of science parks that link innovation and the academia-industry.

For more than three decades, the science parks have continually raised the performance standard of technological progress in Taiwan. By demonstrating successful production approaches and disseminating technology, the parks have not only improved the nation's industrial structure and economic prosperity, but also made a name for Taiwan's high-tech industries around the globe. Taiwan currently has three core science parks located in the northern, central, and southern areas. The Hsinchu Science Park (HSP) was established in 1979 as Taiwan's first science park. It is the most developed science park and has the broadest range of industries. The Southern Taiwan Science Park (STSP) was founded in 1997. It houses complete clusters of optoelectronic, semiconductor, biotechnology, and precision machinery companies. The park is also developing industries dedicated to green low-carbon energy and biotech medical devices. Completed in 2003, the Central Taiwan Science Park (CTSP) is situated amid a major hub of the precision machinery industry.

In accordance with government policy, these science parks offer dedicated spaces along with a wide range of professional advisory and resource referral services. In addition to legal, financial, and accounting advice, these also include technology-business matching advice, marketing assistance, technical and equipment support, prototype development, and venture capital negotiation. The parks have also expanded their one-stop service functions to foster an environment conducive to innovation and entrepreneurialism.

3. Systems Analysis of an Innovation-Driven Economy with Science Park Policy

In this section, systems thinking is administered to identify the relationships that exist among the ecosystem of an innovation-driven economy. To identify the elements and the relationships between the elements of the government-academia-industry collaborative ecosystem, a cross-disciplinary research team was established. Regular meetings and interviews with relevant policy researchers, government agencies and government-funded industry associations, scholars, and industry practitioners were conducted, followed by weekly inner team meetings and monthly inter-organizational meetings and reviews. After the preliminary investigations of the government-academia-industry collaborative ecosystem and a causal loop analysis, the critical elements, variables, and their inter-relationships were identified by the research team. Therefore, the proposed causal loop diagrams have a reasonable foundation, supported by real world practices and peer reviews.

The policy for facilitating collaborative ecosystems aims to understand long range impacts and sustainable developments. Systems thinking and a long range perspective help to ensure holistic viewpoints and mapping are applied to policy implications [8]. Previous studies have proposed that systems analysis can help to better understand and respond to a problem and provide more comprehensive representation [9,10]. From an operational point of view, the systems thinking framework describes the behavior of a system by using causal loops diagrams. Reinforcing feedback loops and balancing feedback loops are identified and the impacts of different feedback loop mechanisms are discussed below. First, we review the feedback loops and the effects of technological innovation and business development on economic performance under a market-driven system. Furthermore, how governmental science park policies can enhance the government-academia-industry collaborations for innovation-driven economy ecosystem is presented by systems thinking. Policy implications for facilitating a self-reinforced ecosystem are discussed from the systems perspective.

3.1. Analysis of the Market-Oriented System

Previous studies have proposed that technological innovations and new business model developments are driving forces for market growth and industrial economics [11,12]. Technological innovation drives business model development that leads to market development and growth. Eventually, growth and better economic performance encourages further investment in technological innovations and reinforces a feedback loop for positive development. Therefore, it is a worthwhile endeavor to identify the underlying feedback structures that exist between key variables for the development of science parks and the ecosystem of high technology industries.

In this paper, five conceptual variables identified as key driving forces to the ecosystem of an innovation-driven economy have been highlighted: (1) technological innovation; (2) the competitiveness of industry clusters; (3) new business development; (4) market performance; and (5) government policy. First, the concept of technological innovation consists of investment and the variety of technological development, relative costs of alternative technology, and government funding for Research & Development (R&D). Second, the concept of competitiveness of industry clusters includes the relative competitive advantage of a specific industry cluster (such as the IC cluster) to drive technological innovation and new business developments. Third, the concept of new business development describes how the connection of technological innovation can be linked to markets and business models, or the boundary of new business and government regulation. Fourth, the concept of market performance consists of market potential, market size (ex: number of adopters and providers), industry sales and profit, economic performance and efficiency driven by various sources, including the establishment of a related early-stage complementary infrastructure, a reduction of consumer learning, network effect, economies of scale, etc. Finally, the consideration of government policy consists of government support as well as grants to R&D for leading industry, resource allocation and performance management, regulations, and incentives to business innovations. The relationships between these key variables are described in the systems analysis and illustrations.

The market-oriented feedback system of technological innovation, business development, and economic performance is described as shown in Figure 1. Three major reinforcing feedback loops and their effects have been identified. First, R1 represents a feedback loop that reinforces the innovation-driven competitiveness through the path. Technological innovations drive the competitiveness of industry clusters. Enhanced competitiveness drives better economic performance and better investment in technological innovations that create a reinforcing feedback to innovation-driven competitiveness in the science parks. Second, R2 represents a reinforcing feedback loop for innovation-driven business development. This feedback loop functions more on creating new business opportunities instead of focusing on competitiveness. Technological innovations drive business development and economic performance. Better economic performance drives better investment in technological innovations that create a reinforcing feedback to innovation-driven growth in the science parks. Third, R3 represents a reinforcing feedback loop for competitiveness by new business development. Technological innovations drive business development and the competitiveness of industry clusters. Enhanced competitiveness drives better economic performance and better investment in technological innovation creates a reinforcing feedback to innovation-driven growth in the science parks.

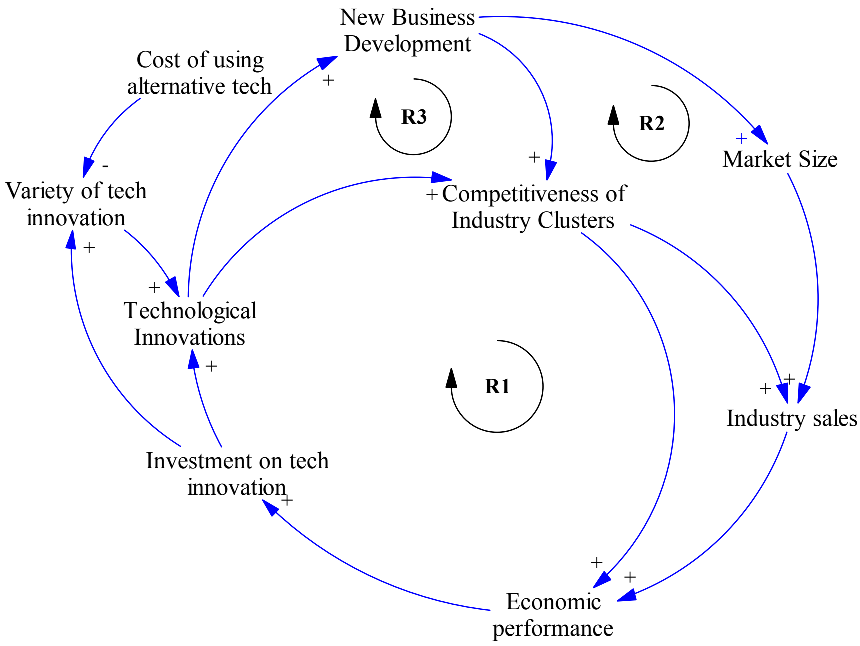

Figure 1. The market-driven reinforcing feedback system of technological innovations, business development, and economic performance.

Based on the aforementioned feedback system, it is recognized that the market mechanism has the value to be an incentive to reinforce the development of technology, business innovations, and economic efficiency. However, the market-driven reinforcing feedback system may not automatically sustain itself. Consistent participation by stakeholders to create policies that enhance the ecosystem are critical aspects of sustainable development.

3.2. Policy Analysis with the Ecosystem of Innovation-Driven Economy

To promote a self-reinforced ecosystem of innovation-driven economy with government-academia-industry collaborations, the science park policy-enhanced feedback system has been proposed as shown in Figure 2. Three policy implications to enhance the ecosystem and sustainable innovation-driven economic development have been identified. First, grants to leading industry R&D could continuously enhance the reinforcing feedback loops for technological innovation and its further impact. Accordingly, reinforcing feedback loops R1-1, R2-1, R3-1 could be sustained to strengthen the feedback effects of innovation-driven competitiveness, business development, and economic performance. Second, a momentum of concentrated resource allocation for performance management could strengthen the innovation-driven competitiveness of industry clusters by forming the reinforcing feedback loop R1-2. It is an intuitively reasonable practice that governmental resources, such as budget and market channels, will be allocated to successful business models with certain performance characteristics. However, from the systems perspective, it must be noted that the common practice might induce two balancing feedback loops (B2-2 and B3-2) that could possibly restrict the development of new business and new technological innovations. While concentrating on established business models with established technology applications, less opportunities for new business development and a higher opportunity cost for alternative technologies might be incurred and become a resistance to further innovation. This counter intuitive feedback structure should be carefully considered and resolved with other kinds of systems approaches. Third, government regulations and incentives to business innovations could help to strengthen the reinforcing feedback loops and deal with the possible policy resistance for an innovation-driven economy. While technological innovations and new business developments are usually required in cross-disciplinary thinking and out-of-boundary actions, appropriate deregulations and incentives to innovative ideas and business models are essential parts of the eco-innovation system. Reinforcing feedback loops R1-3 and R2-3 are intended to strengthen the positive development of continuous innovation in technology and new business development. Furthermore, a balancing feedback loop B3-3 could be formed to reduce the policy resistance to the cost of alternative technology, so that a variety of technology and further innovations are encouraged.

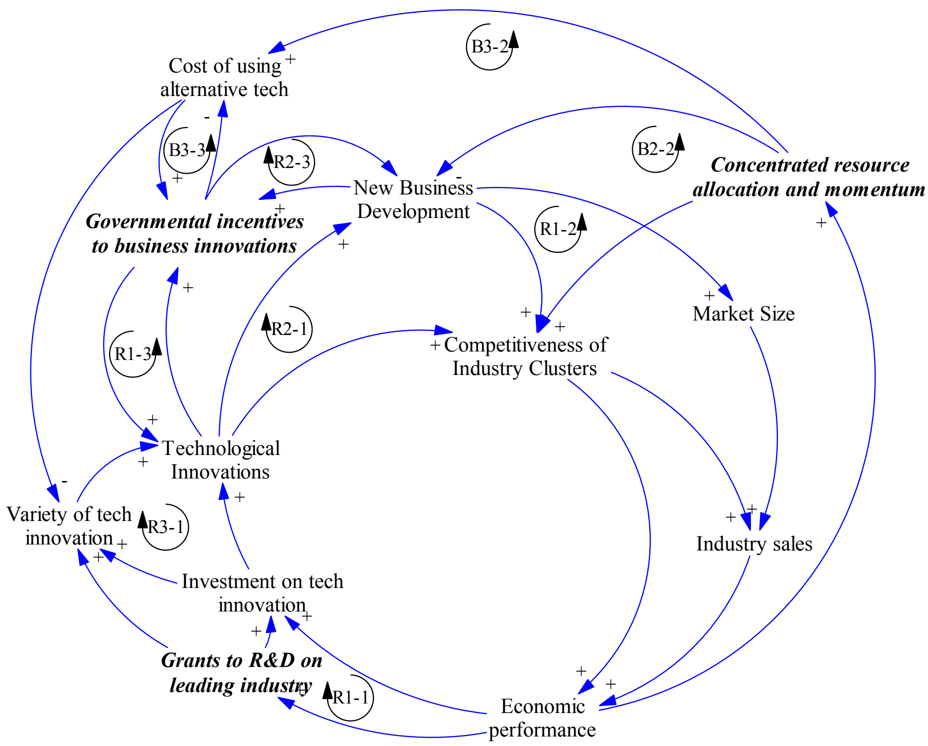

Figure 2. The eco-system of an innovation-driven economy with a science park policy.

4. The Economic Impact of a Science Park Policy

In this section, the contributions of science parks to national economic development and industrial chains are analyzed based on the statistics provided by the Directorate-General of Budget, Accounting and Statistics, Executive Yuan, Taiwan. Government policy has facilitated the focus on science park developments in the past decades. The three science parks have different but complementary focal points of industrial development. They mainly promote the six industries of integrated circuits, computers and peripherals, telecommunications, optoelectronics, precision machinery, and biotechnology. Among these focused industries, integrated circuits and optoelectronics have become the largest core industries. In 2014, integrated circuits brought in the highest sales among all industries at the HSP, while optoelectronics and integrated circuits together contributed 93% and 95% to sales at the STSP and CTSP, respectively. As the feedback structure described in Section 3, government-led science parks continuously receive resources and grants to R&D, leading industry performance and incentivizing business innovation. Therefore, technological innovations, the competitiveness of industry clusters, and new business developments are continuously supported to drive growth and economic performance.

4.1. Economic Added Values and International Trades of Science Parks

In this section, the effect of the high-technology industries in the science parks on national economic development is evaluated by sales and international trades. As shown in Figure 3, in terms of the total sales of science parks from 2004 to 2016, 176% growth is observed in terms of operations scale in the three major science parks. HSP has the largest number of sales in this area over the other two. Given the fact that HSP is the first science park initiated in Taiwan, and is recognized globally as one of the most intensive semiconductor areas, it has undergone a long history of development of science and technology and become the major spot for the high technology industries in northern Taiwan. Based on its successful experience, both the STSP and CTSP were consecutively initiated as latecomers. It is observed that CTSP and STSP are growing steadily, while HSP is maintaining the largest market. At present, HSP covers six locations—the Hsinchu, Zhunan, Tongluo, Longtan, and Yilan parks as well as the Hsinchu Biomedical Science Park—that span a total area of nearly 1400 hectares. These parks must be continuously promoted by reinforcing drive forces that are cautious of balancing loops which concentrate resource allocation and draw momentum from new business developments.

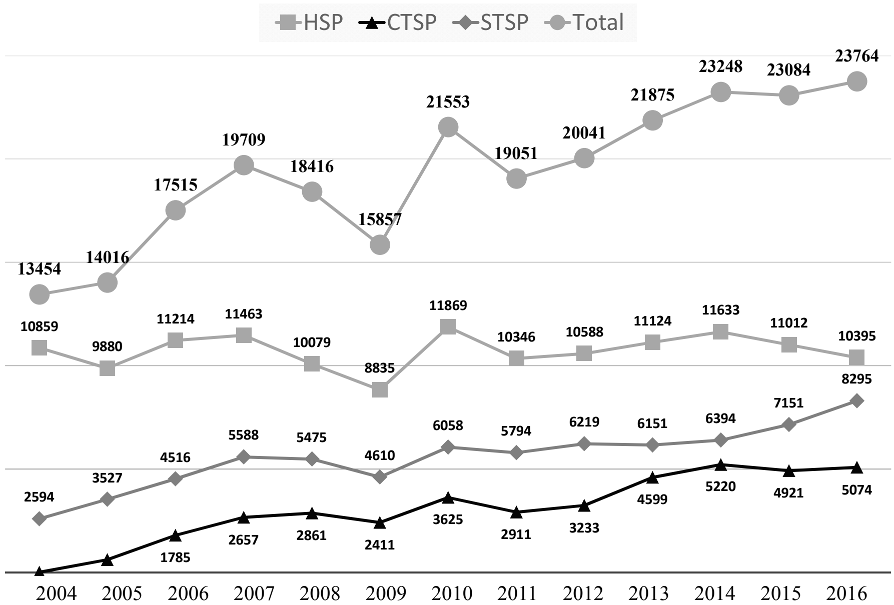

Figure 3. The total sales of science parks from 2004 to 2016. (Unit: 100 Million NTD).

To evaluate the relative position of Taiwanese science parks in the global market and international supply chains, sales in international trades and exports could be one of the performance indices. As shown in Figure 4, a 10 year trend of growth in total sales has been observed (from 2007–2016). The results support the theoretical systems analysis that reinforcing feedback loops drive continuous growth. Specifically, international trades and exports reflect the competitiveness of the industry clusters in the science parks and the linkage with the broader marketplace. The global economy tipped into recession in 2015, which led the annual growth rates of total trades and export trades to decline in Taiwan. However, the share of export trades in total trades have gradually increased and accounted for more than 50% in recent years. This fact indicates the high competitiveness of Taiwan, and shows that these industries are not only capable of satisfying domestic demand but also overseas high-end consumers. This shows an international trend in our total trades as well. As to the average performance of science parks, the share of exports trades in total trades is higher than 60%, which is 65.5% in 2015. The statistical evidence shows positive effect of governmental policies in science parks' development, which boost high export performance in science parks annually.

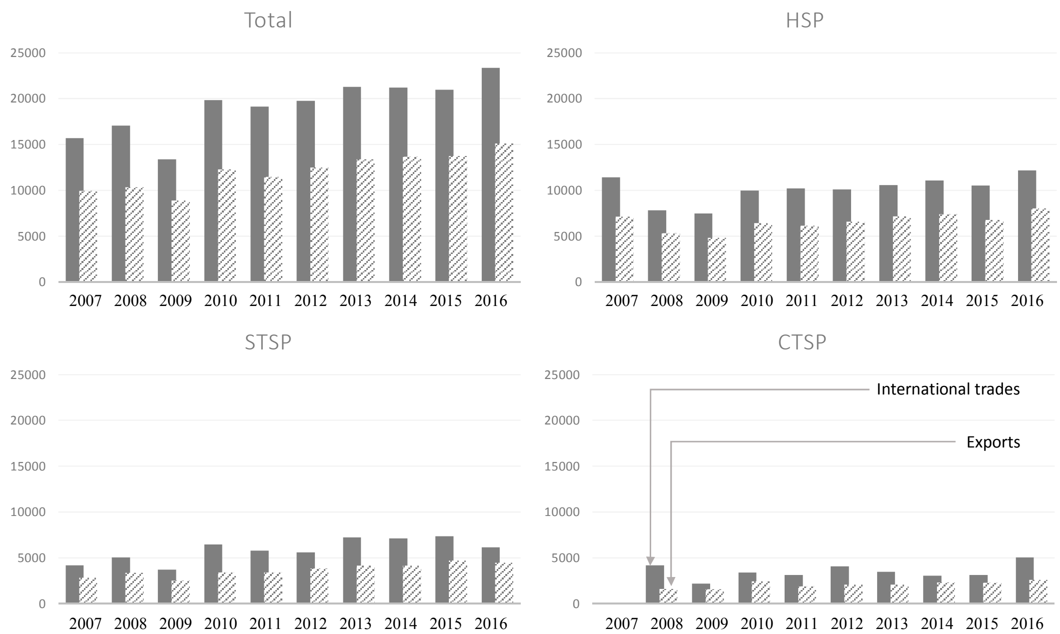

Figure 4. Internal trades and exports of science parks from 2007 to 2016. (Unit: 100 Million NTD).

Among the various export trade items, the top three exports of HSP were (1) wafers of other monolithic digital integrated circuits; (2) other hybrid integrated circuits; and (3) other monolithic digital integrated circuits. The top three exports of CTSP were (1) thin film transistor liquid crystal display devices (TFT-LCD); (2) indicator panels incorporating thin film transistor liquid crystal display devices (TFT-LCD); and (3) chips of dynamic random access memory integrated circuits (DRAM). The top three exports of STSP were (1) wafers of other monolithic digital integrated circuits; (2) parts of liquid crystal devices; and (3) other parts suitable for use solely or principally with the apparatus of heading nos. 85.25 to 85.28.

The results consistently suggest that the effects of high-technology industries in the science parks not only contributes significant economic value to Taiwan as a domestic market but also promotes industrial and technological upgrades to better fit Taiwan in the global economic system. The collaborative ecosystem consisting of technological innovations, new business development, and industrial upgrades is a reinforcing feedback loop that drives growth.

4.2. Number of Firms and Employment of Science Parks

Science parks could drive economic development and social welfare by facilitating entrepreneurial firms and by providing more employment opportunities. The total number of firms in the science parks has steadily increased to 905, while IC firms, Optoelectronic firms, and Biotechnology firms are the major categories of enterprises. Accordingly, more job opportunities were opened and the total number of employment in the science parks has significantly increased.

From a systems perspective, employment is not just for creating job opportunities but for the human capital that drives technology and business innovations. A positive reinforcing feedback between human capital and a firms' competitiveness should be recognized. As shown in Figure 5, in 2004–2013, employees of the integrated circuits industry make up around 45–50%, Employees of the computers & peripherals industry are around 5–6% of all the employees of science parks. Employees of the telecommunications industry make up around 3–4%. Employees of the opto-electronics industry make up around 35–38%. Employees of the precision machinery industry make up around 4–5%. Employees of the biotechnology industry make up around 2%. In 2013, researchers accounted for around 11.3% of total employees in science parks. Based on 2013 statistics, the total number of employment in the science parks accounts for about 2.3% of the total number of employment in Taiwan. However, 2.3% of the labor force was able to contribute about 15% of the total GDP in Taiwan.

The results significantly demonstrate the high value and added economic impact of high technology industries in the science parks of Taiwan. Higher levels of income for the employees in the science parks is observed, as are the subsequent benefits.

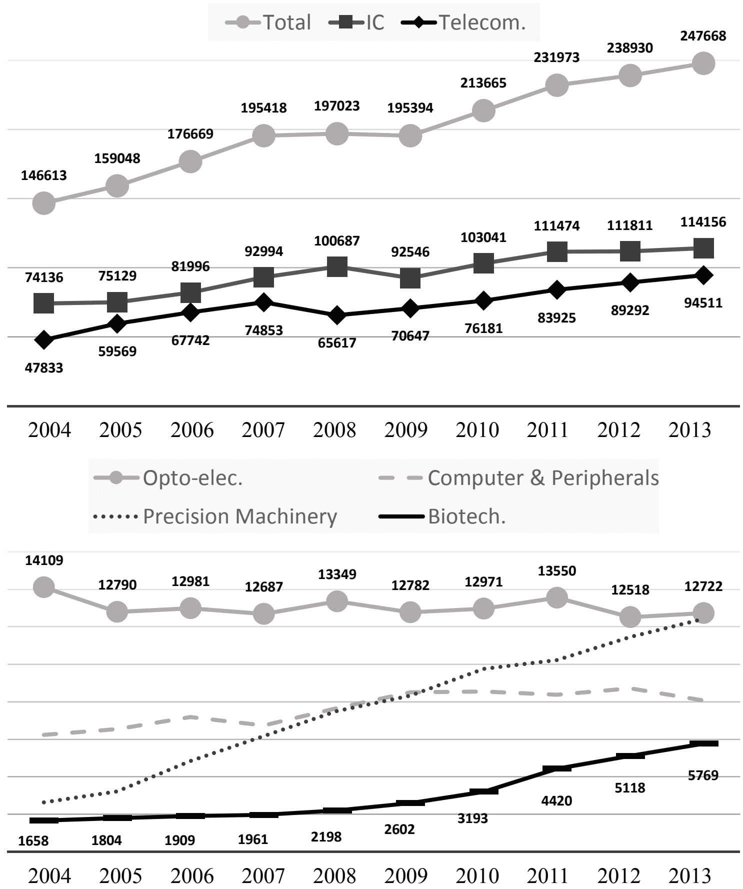

Figure 5. Employment in the science parks and industry clusters from 2004 to 2013. (Unit: person).

5. Innovation of High Technology Industries in the Science Parks

The importance of technological innovation has been explained by the three reinforcing feedback loops in the systems analysis section. The innovation of high technology industries in Taiwan has been continuously facilitated by a government policy intended to strengthen academia-industry links and innovation. Academia-industry cooperative research matches the advanced and practical technologies and knowledge applications present in universities with the needs of private-sector businesses. These projects develop the R&D capabilities of educational and research institutions while encouraging companies to participate in university-based applied research projects. To promote the collaboration of highly innovative research projects, MOST defines the scope of research results and establishes optional models for technology transfer authorization, thus increasing the effectiveness of academia-industry cooperation. In 2014, a total of 813 projects received government funding, 852 companies participated, NT$328 million was raised in corporate matching funds, and 2095 graduate students received training. To develop the R&D capacity and eco-innovation system for the high technology industries in Taiwan, the following innovation policies were promoted:

(1) PIONEER Grants for AIC: MOST has been jointly funding the PIONEER Grants for Frontier Technologies Development by Academia-Industry Cooperation with the Ministry of Economic Affairs since 2013 to encourage international and regionally leading firms to form alliances and engage in cooperative research with universities.

(2) Minor Alliance Projects: Academia-Industry Technological Alliance Projects make use of university researchers' technological capabilities and encourage professors to establish core technology laboratories as a bridge to industry users. Funded by MOST since 2013, these projects encourage academic organizations to build laboratories centered on their research as a new platform for academia-industry collaboration.
(3) From IP to IPO: The purpose of this program is to encourage the establishment of startups by young researchers, promote an innovative, entrepreneurial culture at universities and research organizations, and to foster an environment for the industrialization of R&D results and innovations.
(4) Germination Program: The program accelerates technological diffusion by helping scientific research organizations establish mechanisms for the promotion and use of R&D results.
(5) Industrial Fundamental Technology Projects: The program brings together academic and industrial resources to reinforce the technical foundations of Taiwan's manufacturing industry.
(6) Applied Research Incubation Projects: The program promotes biotechnology integration and an incubation mechanism to evaluate, construct, and connect R&D capabilities along Taiwan's biotech value chain.

5.1. The R&D Intensity for Innovation

Previous studies have proposed that R&D is a key factor for the ability of high-tech firms to compete and thrive under intensive global competition [13–15]. Empirical studies on R&D intensive firms and high-tech industry clusters have proved that higher production economies add value [16,17].

There has been a rising interest in the relationship between research and development (R&D) and firm performance in the high-tech industry. Owing to the intensive competition and rapid advances in innovation, high-tech firms must invest in R&D to maintain or strengthen their market competitiveness. Previous studies [18–20] have argued that R&D is a driving force for productivity, and others have claimed that R&D efforts help to capture market share [21,22] and contribute to the profitability of firms [23,24].

The R&D capacity and performance in science parks has played a leading role in Taiwan. Based on the research of the "National Science and Technology survey" from 2009 to 2014, the number of R&D personnel accounts for around 20% of the total employees of private sectors in science parks, and private R&D expenditure in science parks accounts for 40% of the manufacturing industry's R&D expenditure in Taiwan (as shown in Table 1). In addition, U.S. patents obtained by enterprises in science parks account for over 30% of those obtained by Taiwanese enterprises; and among top ten Taiwanese enterprises who obtain U.S. patents, over 60% are enterprises in science parks.

In summary, the total R&D expenditure in the science parks accounts for more than 48% of the total R&D expenditure in the high technology industries in Taiwan. These significant results suggest the importance of science park developments for the high technology industrial clusters in Taiwan, where R&D expenditure and technological innovations are critical functions.

Table 1. R&D Personnel and R&D expenditure of Science Parks.

Item \ Year	2009	2010	2011	2012	2013	2014
R&D Personnel of Science Parks (Units: Persons)	37,563 (19.14%) *a	42,214 −19.68%	44,560 −19.13%	45,457 −18.95%	47,789 −18.51%	50,773 −19.67%
R&D Expenditure of Science Parks	932.56 (5.9%) *b	1011.13 −4.70%	1081.20 −5.70%	1124.07 −5.60%	1243.97 −5.70%	1352.95 −5.80%
(Unit: a Hundred Million NTD)	(39.7%) *c	−39.30%	−39.30%	−38.60%	−39.80%	−40.00%

*a: Percentage of R&D Personnel of science parks in total numbers of employees in science parks (scientific industries only) during the year. *b: Percentage of R&D Expenditure of science parks in sales of science parks during the year. *c: Percentage of R&D Expenditure of science parks in R&D Expenditure of the Taiwan Manufacturing Industry (private sectors) during the year.

5.2. Patent Developments and Innovation

Similar to the R&D efforts, previous studies have proposed that patents act in an intermediary role that may protect innovations, creativities, and R&D outcomes, contributing to the profitability of firms [23]. Based on statistical results, the number of patents granted by the United States Patent and Trademark Office (USPTO) in science parks has steadily increased from 2011 to 2016. Furthermore, compared with all of the numbers of patents granted by the USPTO in Taiwan, the percentage of patents granted by the USPTO in science parks accounts for more than 30%, and that percentage is up to 49.5% in 2016 (as shown in Table 2). From a world-wide perspective, it is recognized that the Business Enterprise R&D Expenditure as a Percentage of Value Added in Industry in Taiwan is higher than in China but lower than some other countries with government-led science parks, such as the USA, Japan, and Korea. The results suggest the effectiveness of the eco-innovation system and the development of patents in the science parks in Taiwan.

Table 2. Patents Granted by the United States Patent and Trademark Office (USPTO).

Item	2011	2012	2013	2014	2015	2016
Number of patents granted by USPTO in Science Parks	2327 (32.2%) *d	2964 (35.1%)	3023 (31.4%)	4156 (36.7%)	4630 (38.5%)	5137 (49.5%)

*d: Percentage of numbers of patents granted by USPTO in Science Parks in numbers of patents granted by USPTO in Taiwan.

6. Conclusions

To promote science and technology polices and innovation-driven industrial developments, public policy makers need to continuously evaluate the economic impacts and innovations with comprehensive performance indicators. Most importantly, policies for facilitating economic development add value, and innovations are the critical driving forces on the government side. However, a systems perspective is required to recognize the underlying feedback structure of the ecosystem and is a promising approach into the sustainable development of science parks and the innovation-driven economy. Government policy that facilitates positive effects on technological innovations, business development, market competitiveness, and economic performance must be specifically identified with reinforcing feedback loops in the ecosystem. In addition, regulations and incentives to business innovation should not only focus on the reinforcing feedback system but the balancing feedback loops that reduce the policy resistance for innovations as well. Policy implications could thus be systematically discussed and evaluated using systems analysis from a holistic point of view. In this paper, five conceptual variables identified as key driving forces to the ecosystem of the innovation-driven economy have been highlighted with a causal loop analysis. The concepts of economic added values, international trades, employment, R&D intensity, and patent development are applied to a case study of the economic impact and innovation of science parks in Taiwan, which is an addition to the theoretical and practical contributions to the development of the high-technology industries.

Using the benchmarked case study in this paper and applying the lessons learned, we have discovered policy implications that are not limited to Taiwan and applicable for science parks willing to facilitate an ecosystem supported by government participation. Especially for science parks with strong government support, the proposed systems analysis and performance evaluation provides a comprehensive perspective for supporting the innovation-driven economy and the performance evaluation of industrial incubation policies. From a macro standpoint, the integrated economic perspective must be incorporated into the list of factors used for the establishment of nationwide policies that control choice of industry, segmentations, and ecosystem developments. Our research results suggest that a national science parks policy can foster successful development of high-technology industries with significant economic benefit and R&D performance. Although many types of science parks could be funded, the development of government-led science parks is one of the significant types found around the world and worth further investigation. Several policy implications for improving innovation-driven ecosystems are identified based on the proposed systems analysis and case study of science parks. First, a nationwide macro viewpoint is needed for the planning of innovation-driven industrial developments, while the concept of a collaborative ecosystem should be embedded in public policies. Second, when governmental agencies consider high-technology industries to be a national/regional economy, an appropriate economic and innovation index system can better represent the contributions of the high-technology industries and lead the growth strategies. Third, a proper industrial clustering mechanism and innovation ecosystem can further facilitate the high-technology industries to reach the status of an upgraded economy. Fourth, a systems understanding of the underlying feedback structure of innovation-driven ecosystem is important so as to identify the critical success factors and trends necessary for economic development. The utilization of reinforcing and balancing feedback loop analysis could help systematically reinforce growth opportunities and policy resistance. The proposed policy implications including R&D grants for leading industry, resource allocation and performance management, and regulations and incentives to business innovations should lead to improvements in science parks and high-technology industrial development. More innovative and practical indices that accommodate the integration of economy and innovation for specific industrial requirements are recommended for future research.

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