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Technological entrepreneurship in science parks: A case study of Wuhan Donghu High-Tech Zone

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ABSTRACT

Science park has been widely regarded as an effective mechanism to promote innovation and development of new ventures and industrial clusters in a region or country. With a variety of innovation factors such as venture capital and entrepreneurial talents injected into a science park, it demonstrates a positive effect on flowing and converting of knowledge in technological entrepreneurship for emerging economies. In this paper, we constructed an effect model of technological entrepreneurship of a science park in the context of an emerging economy. Specifically, we studied the Wuhan Donghu High-Tech Zone in China. We analyzed the incubation effect of science and technology enterprises, the interaction effect between innovation and entrepreneurship, the synergistic effect between science and technological innovation and system innovation, and the cluster effect and ecological effect. We conducted a system dynamics simulation to quantify the interaction of technological innovation, institutional innovation, technological entrepreneurship and entrepreneurial culture. Simulation results show that a joint action of several innovative subjects and factors promote the development and prosperity of a science park.

1. Introduction

Innovation is an important driver for the development of a country, a region as well as a company (Hekkert et al., 2007; Lamperti et al., 2017). Particularly, those new knowledge-based industries have transformed from traditional factor- or investment-driven to innovation-drive (Lu, 2016; Lu, 2017; Wang, 2017). The mode of an innovation-driven economy is endogenous development (Acs and Varga, 2002), characterized as taking advantage of new knowledge and technology to reform and integrate factors of production (García-Morales et al., 2014; Rasool et al., 2017). Innovation activities can be portrayed as a result of knowledge and resources exchange between players who are mobilized through legitimization activities (Cajaiba-Santana, 2014; Lima, 2016). There is little doubt that innovation is a main source for technology companies to improve their efficiency and to establish long-term competitive advantage (Achi et al., 2016; Huang, 2011). Innovative technology enterprises tend to break the traditional constraint of production factors, and instead, to develop a joint industrial advantage so that they can achieve efficient, intensive, and sustainable development (García-Morales et al., 2014; Grinstein and Goldman, 2006).

Succeeding with a new business is not an easy task for any entrepreneurs. There are huge risks and responsibilities. Entrepreneurs always face challenges such as a lack of adequate resources (Yoon et al., 2015), capacity variance (Demirbas et al., 2011), situational differences (Choi and Majumdar, 2014), and risk taking (MacKo and Tyszka, 2009). To succeed with a new enterprise, entrepreneurs must have all elements, including leadership and organization, people and skills, culture and values, and processes and tools to work in a coordinated manner. Among all choices, science parks provide such a mechanism.

Science parks have been widely recognized for their importance to development of high-tech enterprises and industrial clusters (Lamperti et al., 2017). Gordon and Mccann (2000) suggest that it is a unique regional innovation system that brings together innovation organizations such as enterprises, research institutions, and public services. It is a mechanism that integrates innovative resources including manpower, knowledge, and many other factors (Rutten and Boekema, 2007) to establish one "virtual" location for physical locations and innovation clusters. This is particularly important to emerging economies where a technology catch-up (imitation) strategy is frequently adopted (Fan, 2017). With such a strategy, it is vital to have sufficient interactions among industries, universities and governments (Zhang and Zhou, 2016). In established economies, science parks also play an important role. The difference is that industries are the driving force, universities mainly provide skilled human capital, and the government focuses on

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social and economic polices (Huang et al., 2012; An and Ahn, 2016). For example, Samsung has a highly centralized innovation network, which includes many academic institutions in the U.S. and Japan, and strong collaboration between Foxconn and Tsinghua University in China (Ozcan and Islam, 2014). In another example, Technologically Able Social Entrepreneur (TASE) from the U.S. national laboratories brought the birth of Laminar Flow Clean Room, and National Institute for Nanotechnology Engineering (Chavez et al., 2017).

Among science parks all around the world, Silicon Valley is the most well-recognized benchmark for building a high-tech industrial park (Dorfman, 1983; Klepper, 2010; Wonglimpiyarat, 2016). Its development model provides practical guidance to many science parks in established economies including Cambridge Science Park (Minguillo et al., 2015; Siegel et al., 2003), science parks in Greece (Bakouros et al., 2002; Ratinho and Henriques, 2010), and science parks in Italy (Bigliardi et al., 2006; Colombo and Delmastro, 2002). It also is heavily referenced by science parks in emerging economies including software parks and biotech parks in India (Nagendra and Gopal, 2011; Vaidyanathan, 2008), biotechnology science parks in Brazil (Cabral and Dahab, 1998; Etzkowitz et al., 2005), Xinzhu Science Park in Taiwan, China (Chen et al., 2006; Lai and Shyu, 2005), and science parks in Singapore (Koh et al., 2005).

Emerging economies such as China and Malaysia are actively supporting new start-ups that pioneer in technologies required by new market needs (Li, 2017; Wong and Goh, 2015). Yoon et al. (2015) elaborated policy implications of the construction of East Asia regional innovation system that aims to promote regional entrepreneurship. New technology revolution is also one of the four driving factors of China's economy development in the past three decades (Baark, 2001; Cui et al., 2016; Yang and Li, 2008). Successful entrepreneurship is crucial to the vitality of economy (Bruton and Chen, 2016). The literature has well documented how technological entrepreneurship, including city and town-based enterprises, private start-ups, and transformed state-owned enterprises, triggered socio-economic changes in China, from a relatively closed and slow growth to a sustained industrialization process (Contractor and Kundu, 2004; Yang and Li, 2008).

The development path and characteristics of science parks in China are significantly different than that of Western countries. High-tech zones are common in China and they provide a good living environment for the study of government-university-enterprise linkage for technological entrepreneurship. As of October 2015, the number of national high-tech zones in China has increased to 145. These high-tech zones have rapidly become an important carrier of independent innovations in China. They have successfully supported industrial upgrading and technological progress in China (Cooke and Leydesdorff, 2006). Specifically, science parks offer a unique context for the sharing of knowledge, skills and best practice within a geographic area (Venkataraman, 2004; Yoon et al., 2015), and lead to superior performance by simultaneously integrating resources and collaborating with partners (Cui et al., 2016; Pillania, 2012). Most science parks, such as Zhongguancun science park and Ningbo science park are guided by municipal governments in China. The industrial policies fundamentally adjust the allocation of social capital and mitigate constraints on entrepreneurship (Urbano and Aparicio, 2016; Wu et al., 2010). In contrast, spontaneous creation and research institutions promote the formation of most western science parks (Yoon et al., 2015). Entrepreneurs are more technology-driven, whether the innovation is of a world-changing nature or merely efficiency improvement. The original innovation determines the fundamental differences in technological entrepreneurship (Su and Hung, 2009). In addition, factors such as average R&D investment, labor productivity, number of employees, number of companies, and capital have significant performance implications on technological entrepreneurship derived from science parks (Chan and Lau, 2005; Gupta et al., 2014; Lee and Yang, 2000).

The remainder of this paper is organized as follows. In Section 2, we propose a theoretical paradigm for technological entrepreneurship and socio-economic changes about science parks. We then analyze basic functions of science parks to build an effect model for technological entrepreneurship, considering the differences between emerging and established economies. In Section 3, we conduct a case study on Wuhan Donghu High-Tech Zone, illustrating the five effects identified in the theoretical model. In Section 4, we perform a simulation study on the effect of technological entrepreneurship. The simulation model explores the interaction effect among technological innovation, institutional innovation, technological entrepreneurship, innovation and entrepreneurial culture. We conclude the paper with a summary of findings and policy recommendations on the development of science parks in emerging economies.

2. Theoretical framework

2.1. The CAER paradigm

Science park is a catchword for many types of industrial agglomeration, including high-tech zones, science cities, industrial parks, high-tech regions, science-based industrial parks (Isaksen, 2001). A variety of technological innovation factors are utilized intensively in sciences parks. Through preferential investment policies and special management systems, high-tech enterprises assimilate a large amount of external funding, advanced technologies, and management expertise and transform them into enterprise resources. A science park is indeed a system that can be studied from four aspects: C (factor Convergence), A (industrial Agglomeration), E (industrial Ecology), and R (Radiation). They interact as a synergic system (Fig. 1).

2.1.1. Factor convergence

Resources are a necessary condition for enterprise growth and development. Resource-based view (RBV) provides a convincing explanation for competitive advantage of a company. RBV regards an enterprise as a collection of both tangible and intangible resources (Wernerfelt, 1984). Enterprises hold heterogeneous resources that determine the conversion from a short-run competitive advantage to a sustained competitive advantage. Clearly, identification and acquisition of such resources for start-up enterprises is an extremely difficulty endeavor. Entrepreneurial opportunities emerge before agents. Only those agents with unique insights can carry out these unexploited opportunities (Alvarez and Busenitz, 2001; Powers and McDougall, 2005). An entrepreneurial rent is eared with such opportunities, if succeeded. This serves as a two-way guidance for government policies. Emerging technologies lead to the construction of science parks. When a variety of innovative and entrepreneurial elements fully converge in a certain space, their mutual reinforcement provides an entrepreneurial path.

2.1.2. Industrial agglomeration

An industrial cluster, according to Porter's theory, is a geographically close group of enterprises and institutions, gathered by commonalities and complementarities (Porter, 1998). Clusters are an organization of resource aggregation. They can be highly effective in competition because they can offer the position of either an arm's length market or hierarchies (Tan, 2006; Williamson, 1978). Recently, technological and sociological shifts have reshaped the market structure and entrepreneurial form (Gorkhali and Xu, 2016; Gorkhali and Xu, 2017; Nan et al., 2013; Peng et al., 2016; Wekerle et al., 2017; Xu, 2011; Xu et al., 2014). The boundary between market and hierarchies is gradually vanishing. Industrial systems built on element agglomeration networks have become the main mechanism to obtain core competencies for companies in clusters.

2.1.3. Industrial ecology

Industrial ecosystem is a relatively new business mode that shifts the focus from individual manufacturing processes to industries (Frosch

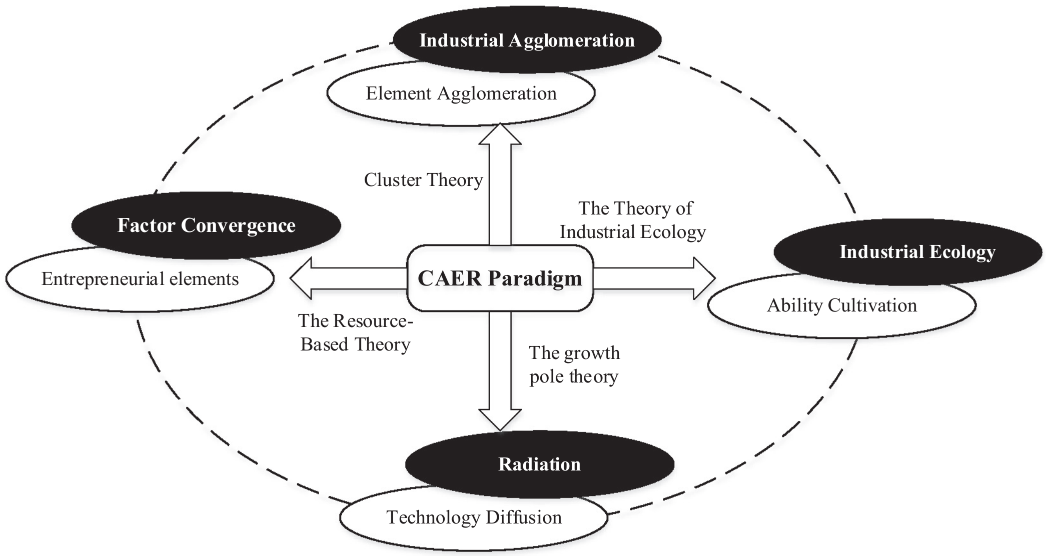


Fig. 1. The CAER paradigm for technological entrepreneurship and socio-economic changes in science parks.

and Gallopoulos, 1989; Marsden and Smith, 2005; Tan et al., 2010). Iansiti and Richards (2006) regard industries as interactive and connected networks of organizations or "industrial ecosystems." Members of industrial ecosystems such as customers, suppliers, leading producers, business associations and standardization bodies have an independent mode of operation but together they form a strong system (Wu et al., 2017). The interrelationship among these organizations facilitates a dynamic exchange of materials and resources within the ecosystem. In such an ecosystem, energy consumption and resource allocation tend to be optimized because semi-finished products or even waste can serve as raw materials for others, hence the waste level and losses are minimized (Wu and Olson, 2010).

New venture development is a complex ecosystem. In such a system, non-linear dynamics relevant to new venture emergence is ubiquitous in the form of technological systems and evolution (McKelvey, 2004). Similarly, non-linear dynamics exist in entrepreneurial activities, reflected by entrepreneurs' creativity, vision, commitment, and ability (Surie, 2017). Different abilities and habits of entrepreneurs are cultivated to create new products and drive market processes, just like in a biological ecosystem.

2.1.4. Radiation

Impact of entrepreneurial activities normally exceeds the sum of economic benefits of startup companies, and brings about a range of spatial agglomeration, or radiation. Perroux (1950) states that if the economic space of a dominant effect is seen as a force field, then the propulsion unit located in this area can be described as a growth pole. According to the growth pole theory, the propulsive pole is a dynamic and highly organized business unit which revolves around the leading industries and drives growth in other sectors through a multiplying effect (Sternberg, 1996; Thomas, 1975). Growth does not appear on all occasions, but at some growth points or poles with different intensities. These growth points or poles spread out through channels and cause different effects on the economy as a whole (Plummer and Taylor, 2001).

A science park is a growth center that drives economic growth and social development of surrounding areas. Technological entrepreneurial activities guided by a science park distribute in a spatial manner with different intensities, exchange resources in different ways (Aparicio et al., 2016). Subsequently, a variety of entrepreneurial elements from the science park spread across the surrounding underdeveloped areas at a certain stage of development, i.e., the trickle-down effect. This leads to a narrowed gap between surrounding areas.

2.2. Emerging versus established economies

There are two major ways to create a science park: spontaneous creation, and government guiding (Su and Hung, 2009). Silicon Valley, the most successful science park, is a representative of the former. Many countries try to imitate Silicon Valley's success into their own science parks. Since then, a large number of science parks have emerged with geographic and spatial agglomeration. Interestingly, they show distinct differences in properties between emerging and established economies.

The combination of government guidance and market needs plays a crucial role in the development of a science park (Chung, 2002, Su and Chen, 2015). Science parks in established economies are almost always created due to the interaction between scientists and venture capitalists (Su and Hung, 2009). Research institutions take a leading position. They create knowledge, technology, and an academic atmosphere to support entrepreneurs. Most firms in the area are academic spin-offs. The spontaneous success factors can be explained as that the government provides funding for scientific research institutions to carry out technological innovation and creation, while venture capital supports marketization of such innovations and entrepreneurship (Cui et al., 2016; McAdam and McAdam, 2008). In contrast, science parks in emerging economies are always a government planned regional innovation area that is devoted to high technology development (Lau and Lo, 2015). As investment systems are not mature in most science parks, local governments often set up financial institutions to support the normal operations of start-ups.

Big differences exist in human resources availability and training. Human resources are crucial to the success of the whole science park (Lofsten and Lindelöf, 2002). In established economies, science parks are home to numerous research universities and institutions. These world-leading universities and research institutions provide a solid foundation for scientific research, which transform into economic benefits through entrepreneurship (Lai et al., 2014; Tan, 2006). While leading industries enjoy the scientific progress, ambitious talents are offered exciting entrepreneurial opportunities. Through cooperation with surrounding universities and training institutions, for example, Xinzhu Tsing Hua University in Taiwan, China, talents are well cultivated to fill suitable position, as in the case of Bangalore Software Park. In contrast, science parks in emerging economies are more valued by local governments. Regional innovation systems are formed to integrate government resources, local universities, industry institutions, and even independent scholars in the form of vertical projects (Bakouros et al., 2002; Liu et al., 2016; Su and Chen, 2015; Wang et al., 2007).

Table 1
Differences between science parks in emerging and established economies.

Category	Established economies		Emerging economies		
Name	Silicon Valley	Tsukuba	Bangalore	Hsinchu	Zhongguancun
Driving factor	Market	Government (support)	Government (support), market	Government (guide), market	Government (guide), market
System	Intellectual property protection, legal service	Vertical leadership, legal services	Government support, legal services	Programs guidance, stock-based compensation, legal services	Government support, legal services
Personnel training	Stanford University, Northwestern Polytechnic University, etc.	Government, University of Tsukuba	Universities, training institutions	National Chiao Tung University, National Tsing Hua University	Peking University, Tsinghua University, etc. government, enterprises
Industry	Electronics, computers, biology, space, etc.	Space, electronics, physics, etc.	Information technology	Optoelectronics, computer, communication, etc.	Electronic information, biomedicine, aerospace, etc.
Culture	Open, competition,	Modern Utopia.	Work is fun	Freedom, democracy	Tolerating failures

Moreover, there are obvious cultural differences between science parks in emerging and established economies (Ge and Wang, 2012). Take Zhongguancun, a science park in Beijing, China as an example, a culture of failure tolerance attracts innovators and entrepreneurs from all over the world. They are encouraged to take risks in technological entrepreneurship. In comparison, science parks in established economies tend to be relatively more conservative in terms of risk-taking. The Western entrepreneurial culture emphasizes more on innovation and freedom. We summarize the above differences in Table 1.

2.3. Effects of technological entrepreneurship in science parks

With factors such as location, nature, culture, market, system in place, innovation subjects including scientific research institutes, enterprises, colleges and universities constitute a comprehensive system that is deeply coupled. The system aims to transform technological achievements into economic performance. Based on explanations and arguments on the type of science parks presented earlier, we propose a model that shows five effects of technological entrepreneurship (Fig. 2).

2.3.1. Incubation effect

The incubation effect of a science park is reflected in incubation of high-tech R&D achievements and enterprises (Mas-Verdú et al., 2015). An incubator, or accelerator, is a social organization that serves small and medium enterprises. It is set up to introduce promising research to entrepreneurs and support them in their entrepreneurial effort. An incubator provides necessary resources and management expertise to start-ups (McAdam and McAdam, 2008). The goal is for a start-up to develop into a successful enterprise, independently managed and assumes the sole responsibility of profit and loss. The interaction between incubators and original industries promotes the formation of a leading industrial structure.

2.3.2. Interaction effect

Innovation is the foundation of entrepreneurship, and a prerequisite to maintaining creativity and competitiveness of a science park (Lai et al., 2014; Tan, 2006). Market demand and revenue are key drivers of innovation both to enterprises and universities. A positive loop is often observed in this process. Better innovation drives enterprises to invest more resources to further improve the innovation for better revenues, which leads to a higher level of regional economic development. This further stimulates market demand for innovation and technological entrepreneurship. Meanwhile, universities and scientific research institutions may also increase research funding and personnel level due to a higher level of market demand for innovation.

2.3.3. Synergistic effect

The change of innovation and institution is an organic system of mutual connection, restriction, and interaction (Pillania, 2012). Science parks promotes technological innovation. With technological innovations come new possibilities that may re-shape an existing industry. The impact includes new products and new production processes. On the other hand, it is an extrinsic incentive for the government to complement innovation and entrepreneurship with additional funding and policy support.

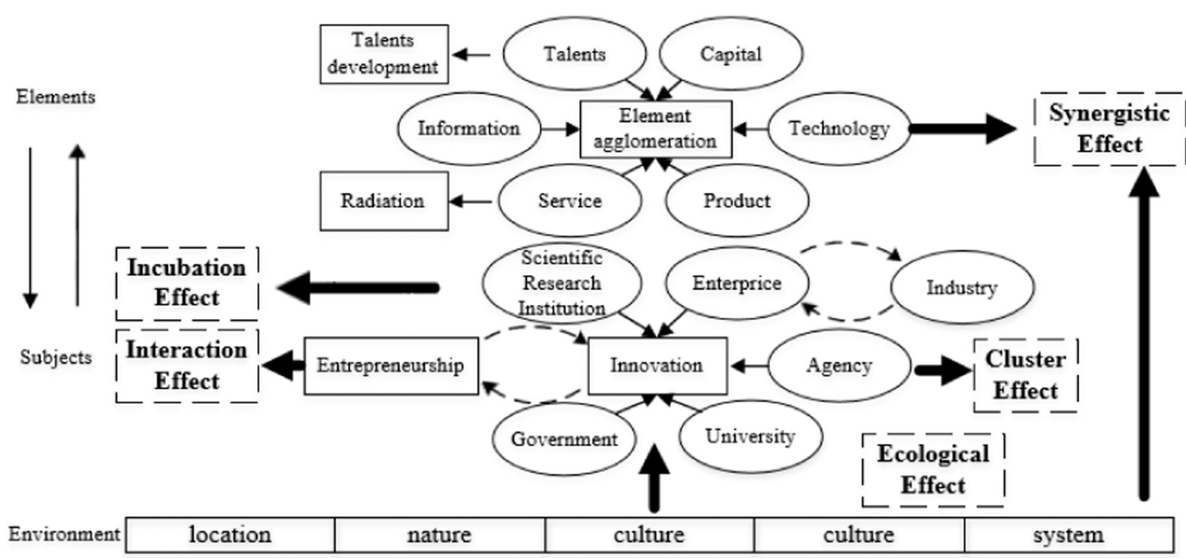


Fig. 2. Effects of technological entrepreneurship in science parks.

2.3.4. Cluster effect

The establishment of a science park links enterprises in a high-tech industry with relevant institutions (Delgado et al., 2014). According to the literature on industrial value chain, when a large number of enterprises gather in a particular region to gradually form enterprise clusters and groups, there is a clear phenomenon of piling up. Further, a science park often is composed of upper, middle and lower segments of core industries and external support industrial systems. Communications among them forms a spatial organic organization structure around the leading industry that promotes the diffusion of knowledge, exchange of new ventures, and integration of industries (Sachdeva et al., 2016).

2.3.5. Ecological effect

Originally a term in biology, an ecosystem is a system that takes on the flow and transformation of matter and energy (Oh et al., 2014). The "population" of such an ecosystem is mainly composed of universities, research institutions, and intermediaries. It supports a variety of "actors," including capital, technology, talents, and entrepreneurs. Enterprises are in different links of industrial chains and environmental support systems. All these elements are inter-connected. An enterprise in a science park carry out different innovations, from low to high, and simple to complex. The process of innovation and diffusion is also the process of the ecosystem to achieve a dynamic balance.

3. Case study: Donghu High-Tech Zone

3.1. Donghu High-Tech zone

Wuhan Donghu High-Tech Zone is one of the first Chinese National High-Tech Industrial Development Zones approved by the State Council. It was established in 1988 (Fig. 3). Donghu High-Tech Zone was established as a National Optoelectronic Industrial Base and a National Biological Industrial Base. In 2011, Donghu High-Tech Zone was designed as one talent base of Central-governmental Enterprises. It also has been defined as a mass entrepreneurship and innovation demonstration base since May 2016.

Donghu High-Tech Zone is located in a district named Hongshan that is southeast of Wuhan. Its total area is 518.06 km^2. In the zone there are 58 universities and 71 national research institutes, including Wuhan University, Huazhong University of Science and Technology, Wuhan University of Technology, and Wuhan Branch of Chinese Academy of Sciences. The role of Wuhan Donghu High-Tech Zone has become increasingly significant in economy development of Hubei province.

3.1.1. Economic contributions

Total revenue of Donghu High-Tech Zone reached 852.6 billion (CNY) in 2014, and exceeded 1 trillion in 2015.

3.1.2. Technological contributions

Since its establishment, the annual growth rate of the number of patent applications consistently exceeds 36%. There are many significant technological achievements in the field of optical communication, biomass energy, numerical control, laser and other fields that are related to Donghu High-Tech Zone.

3.1.3. Industrial contributions

Presently, Donghu High-Tech Zone has 16 national industrial bases, including photoelectron information, information security, laser technology, automotive electronics, and Geo spatial information. There are 50 major industrial projects in Wuhan, including the largest research and development center of Huawei in the world. Hubei provincial government finances a special fund to support 16 strategic projects, include Wuhan Xinxin, Huaxing Guangdian, and Wuhan Tianma, whose sales revenue reached 4.742 billion (CNY).

3.2. Incubation effect

Donghu High-Tech Zone employed a service mode named "Incubation + Acceleration." The zone offers a range of services to science and technology small and medium enterprises (SMEs). There are 72 incubators and accelerators and 25 of them have been identified as national ones, including 14 new forms of science and technology enterprises. Donghu High-Tech Zone has five types of incubators: *Comprehensive incubators* have no restrictions on industries or fields. They help adopt and transform high-tech achievements and promising small technological enterprises. One such incubator is Wuhan Donghu New Technology Venture Center. *Specialized incubators* only work in certain industries, technologies, or talents to provide professional space and services. Wuhan Creative Industry Incubation Center is one example. *University Science Park* (e.g., Wuhan University National University Science Park) relies on resources of universities to serve and support technological innovations and ventures for universities (Quintas et al., 1992). *Incubators of international cooperation* focuses on cooperate with foreign institutions. They will set up incubators overseas, for example, China-US Technological Innovation Park. *New-type incubators* provide specialized services. They customize cultivation models for enterprises in different stages. Table 2 summarizes different incubation modes in Donghu High-Tech Zone.

Incubators provide more resources for enterprises throughout their lifecycle (McAdam and McAdam, 2008). Incubation services at Donghu High-Tech Zone have improved in terms of capital, technology and

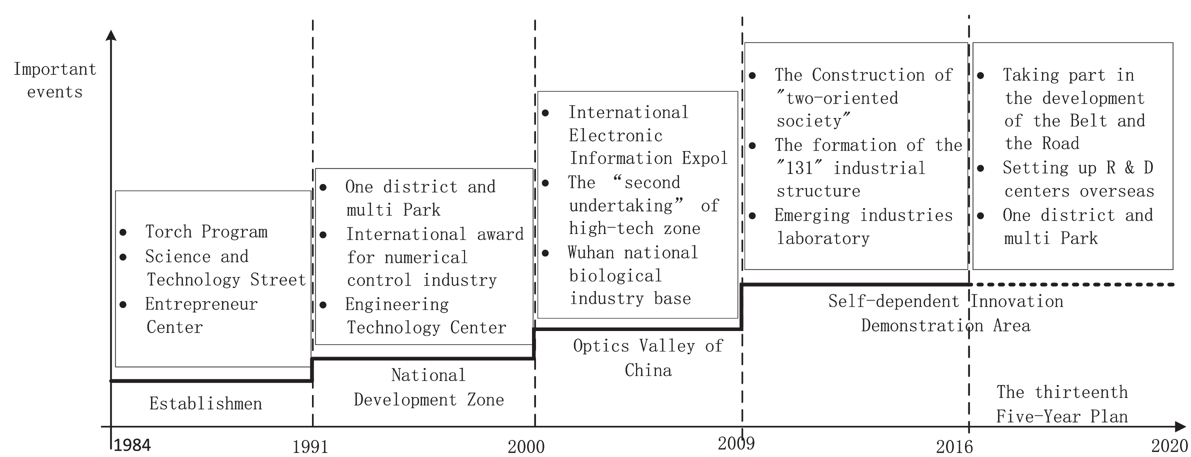


Fig. 3. Timeline of Wuhan Donghu High-Tech Zone.

Table 2
Incubator modes in Donghu High-Tech Zone.

Incubator mode	Characteristics
Entrepreneurial activity & open platform	Supply integrated venture services about online and offline resources by organizing festivals.
Free business counseling & Angel Investment	Invite business mentors to provide business counseling for enterprises.
Open platform & Angel Investment	Open platforms for different participants to exchange information and share resources.
Internet open platform	Provide social networks, technical professional service platforms and industry resources for mobile Internet enterprise.
Community O2O & interaction design	Provide Internet open source hardware platforms, open laboratories, processing workshops and other services for makers.

information. Different incubator modes provide multiple financing channels and entrepreneurial resources platform for enterprises. Capital structure can be adjusted to suite different needs of an enterprise. Incubators also provide necessary technologies, talents, platforms, and other resources to support technological innovation of enterprises in different stages of life cycle and in different industries. Incubators establish platforms to help participants coordinate and transport information and activities. Just like industrial associations, incubators can encourage enterprises to comprehend the latest trends of an industry and policies.

The incubation effect is manifested by the number of new enterprises. The number of newly registered enterprises in Donghu High-Tech Zone is rapidly increasing. The zone has looked at the number of sss enterprises as an important metric for economic development. A Gazelle enterprise, as defined by "Silicon Valley Index," is a public-owned company with an initial income of $10 million or more, and an annual income growth rate of 20%+ for the latest four years. Fig. 4 reports both numbers. Further, the average growth rate of net income of Gazelle enterprises are higher than the average growth rate of the zone.

Wuhan Overseas Scholar Business Park was founded in 1998 by Wuhan government and Wuhan Donghu High-Tech Zone. It is a non-profit public welfare institution who provides a full course of professional services to help overseas scholars to start businesses. It has operated standard incubators with a total of 69,000 square meters. There are near 200 enterprises under incubation. More than 700 enterprises, covering fields of biological medicine, electronic information, and Aero-Space have successfully graduated. The Park established four special industrial districts: Optical Center, Biological Center, Software Center, and Integrated Circuits Center.

Leveraging special policies such as talent development, technological innovation, honor encouragement, and financing, the Park has supported overseas Chinese talents to engage in corporate events like Sci-tech research, production, operation and counseling service. Moreover, the Park has cultivated a large number of venture enterprises for different industries, e.g., Wuhan Dopod Communications CO., Wuhan Aojie Technology Corporation Company, Proteintech Group and Wuhan Welltrans O&E Co. Wuhan Overseas Scholar Business Park has since been an exemplary incubator model for China. It has received numerous awards, including "China High-Tech Pioneering Service Center" (2006), Hubei "3A Science and Technology Business Incubator" (2014), and Counseling Service Station for a National High-tech Enterprises. Further, the Park served as a significant talent pool for key industries in Donghu High-Tech Zone. Development of entrepreneurial activities and innovation achievements in the Park is a major force for the Zone to promote innovation.

3.3. Interaction effect

Since its inception, Donghu High-Tech Zone has consistently increased input to technological innovations, and achieved a substantial improvement in both quality and quantity of innovations. Research and development (R&D) expenditures accounted for more than 60% of internal expenditure on science and technology projects every year. As illustrated in Table 3, total earnings of Donghu High-Tech Zone almost increased by a factor of two during 2011 and 2014. In 2014, the number broke the one trillion (CNY) mark for the first time. The number of patent applications and authorizations also increased steadily.

To promote certain strategic industries such as optoelectronics engineering, Donghu High-Tech Zone built eight industrial technology R&D institutions to provide a great environment for nurturing and fostering enterprises. By 2015, the hatching enterprises have exceeded two hundred. 110 companies completed incubation to realize an average sales revenue of 413 million (CNY). Donghu High-Tech Zone has set up 39 industrial technology innovation consortiums, including 8 national ones. Such forum events gather experts and scholars from certain fields or industries, enhancing technical exchange and cooperation. Examples include "Optics Valley of China" Optoelectronics Worldwide Fair, and the fourth Seminar of Wuhan Automotive Electronics Development. Presently, Donghu High-Tech Zone has 444 technology innovation platforms at or above the provincial level. These platforms have provided 22,705 services to enterprises.

Donghu High-Tech Zone also shows a significant effect for surrounding enterprises on knowledge sharing, technology update, and market expansion. Innovation activities in Donghu create a lots of business opportunities for enterprises and promote the level of entrepreneurship. As the number of businesses in the high-tech zone exceeds a certain level, entrepreneurial spirits reach a new high level. At the same time, the better the business environment, the higher the level of regional industrial innovation.

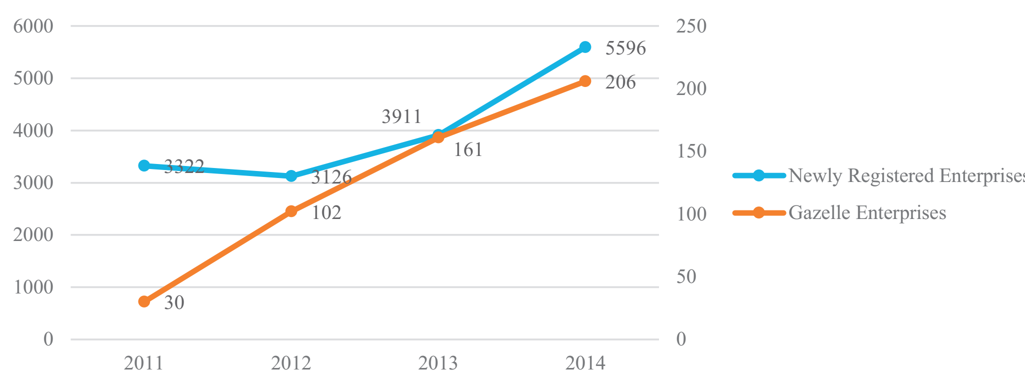


Fig. 4. Number of new and Gazelle enterprises (2011–2014).

Table 3
Donghu High-Tech Zone (2007–2014).

	2007	2008	2009	2010	2011	2012	2013	2014
Internal expenditure on science and technology (Billion CNY)	5.33	6.44	8.88	12.44	15.61	20.16	26.35	32.05
R&D expenditure (Billion CNY)	3.46	5.60	5.04	7.87	10.53	14.99	16.87	20.73
Total earnings (Billion CNY)	130.6	175.9	226.1	292.6	381.0	500.6	651.7	852.6
Patent applications (Unit)	2930	3429	4121	5303	7597	10,529	13,021	14,557
Patents authorizations (Unit)	1468	1754	2173	3985	4634	6963	8501	9533

Table 4
Key policies in Donghu High-Tech Zone.

Reform and opening	Business license first; record system; credit supervision mechanism; platform construction
Special zone of capital market	Offer subsidies to financial institutions; Reward financial institutions for granting of loans; Reward guarantee agencies for providing guarantees; Subsidy and incentives for scientific and technological insurance.
Talent zone	“3551 Optics Valley Talent Program”; Liaison office of bringing in overseas talents; Innovative and venture services for top talents; High-level talent services
Science & technical new town	Cloud box data center platform; Innovation pilot of land management; Reform of performance appraisal

3.4. Synergistic effect

A high degree of synergy between technological and institutional innovations characterizes Donghu High-Tech Zone. In December 2009, the State Council approved Donghu High-Tech Zone to build a national innovation demonstration zone. Donghu High-Tech Zone is charged to take advantage of educational and human resources, and innovative systems and mechanisms to play a leading role in China's reformation. As of now, Donghu High-Tech Zone has helped develop more than 50 supporting policies in taxation, finance, investment, innovation and industry development. Table 4 shows some key policies.

To examine the effect of innovation and entrepreneurship policies in Donghu High-Tech Zone, a questionnaire survey was conducted. Using a Likert scale, the questionnaire is divided into multiple dimensions: reform, opening up of government policy, characteristics of science and technology new town. Respondents were from different categories, including enterprises (38%), universities and research institutes (28%), experts (12%), government (10%), and financial intermediation (12%). Table 5 reports the weighted average scores.

Results show that reform and opening have the strongest effect on scientific and technological innovations of Donghu High-Tech Zone. Compared with other respondents, financial intermediations have a lower level of recognition for entrepreneurial culture and activities in Donghu High-Tech Zone. The government believes that the effect of innovation policy is significant. Universities and research institutions give a more balanced evaluation on each dimension. Their view is that the effect of policies on innovation and entrepreneurial activities of universities and research institutions is weaker than that of financial intermediaries or enterprises. For experts, the effect of policy implementation is slightly less than the desired level, especially on talent acquisition, suggesting that the policy requires a major enhancement or a revision.

3.5. Cluster effect

Supported by the government policy on economic development, the number of venture enterprises in Donghu High-Tech Zone grows steadily. Technological innovation and entrepreneurial activities effectively promoted incubation, acceleration, and growth of enterprises. Interaction and communication among enterprises in the Zone has led to the formation of an intensive entrepreneurial community. As a result, a new industry development pattern formed in Donghu High-Tech Zone. The Zone is dominated by photoelectron information, bio medicine, energy conservation and environmental protection, high-end equipment manufacturing and modern service industries. The Zone has achieved numerous technological innovations, which contributed substantially to the economy of Hubei Province (Table 6).

In 2014, total income of the photoelectron information industry in Donghu High-Tech Zone exceeded 300 billion (CNY). R&D capabilities of optical fiber cables, optical transmission, and optoelectronic devices led peers in China. Production scale of optical fiber and cable ranked first in the world. Each year, Wuhan hosts the “Optics Valley China” international conference on photonics and optoelectronics. Revenue of the biological industry in Donghu amounted to 65.14 billion (CNY) in 2014. Scientific and technological enterprises in Wuhan Optics Valley biological city have achieved significant progress in tumor detection, drug discovery, and other new technologies, for example, “Tumor vesicle mediated chemotherapy,” a brand new technology for the treatment of malignant tumors, and the world's first integrated soft ureteral catheter. The energy saving and environmental protection industry has shown a trend of diversified development. The technology of flue gas desulfuration has demonstrated its effect. There is a breakthrough in the treatment technology of solid waste. In the high-end equipment manufacturing industry, intelligent equipment manufacturing advances quickly, for instance, China's first industrial cloud robot effectively uses “robot + Internet.” Industry convergence in Donghu is accelerating with a fast development of science and technology, and the Internet has given another push to the “Internet +” new industry form.

FiberHome Technologies Group is the largest enterprise located in the Optics Valley and the birthplace of optical information technology in China. Since inception in 1974, FiberHome has become a unique high-tech enterprise that covers the fields of optical fiber, wireless, and data communication technologies in China. Moreover, FiberHome is the “Key Laboratory of Optical Fiber Communication Technology and

Table 5
Survey results on Donghu High-Tech Zone.

	Financial intermediation	Government	Experts	Universities & research institutes	Enterprises
Reform and opening	6.45	6.84	5.23	5.28	6.10
Special zone of capital market	6.25	6.66	4.89	5.11	6.07
Talent zone	6.28	6.78	4.67	5.14	6.21
Science & technical new town	6.10	6.74	4.84	5.09	5.88

Table 6
Income and growth rate of industries (2011–2014).

	Photoelectron information industry	Biological medicine industry	High-end equipment manufacturing	Modern services	Energy conservation and environmental protection
2010	107.11	24.80	41.43	45.92	40.51
Growth rate	28.2%	23.1%	18.4%	24.0%	17.2%
2011	145.03	30.21	50.89	60.94	48.56
Growth rate	35.4%	21.8%	22.8%	32.7%	19.8%
2012	192.73	40.11	63.45	100.23	65.40
Growth rate	32.9%	32.8%	24.7%	64.5%	34.7%
2013	268.57	51.23	79.85	161.55	78.92
Growth rate	39.4%	27.7%	25.8%	61.2%	20.7%
2014	367.86	65.14	100.53	217.90	93.48
Growth rate	37.0%	27.2%	25.9%	34.9%	18.4%

Network in China", "Asia Pacific Telecommunication Union Training Center", and a member of the first batch of "national innovative enterprises." Within 30 years, FiberHome has achieved the leap from a small enterprise in a developing country to a global leader in several areas. Meanwhile, FiberHome has recorded 500 major scientific and technological achievements, with more than 90% commercialized. FiberHome has more than 3000 patent applications, exceeding 20% of the total number of patent applications in Donghu. The company has reached 5 international standards, and more than 500 national and industrial standards. FiberHome has established optical fiber and cable manufacturing base, Wuhan Industrial Park, wireless optical communication industrial park, optoelectronics industry park building, research and production base for Fujikura Fiberhome bar. The company has branches in multiple Chinese cities, including Changchun and Beijing, and industrial bases in Nanjing, Xi'an and Chengdu. In recent years, the company has expanded overseas to set up Accelink Technology Co., in the United States, a fiber optic produce base in Ecuador, an IPX company in Denmark, Accelink Europe Limited in Germany, and a joint innovation center in Malaysia and Indonesia.

3.6. Ecological effect

Intensive interactions with government, enterprises, universities, and agencies have led Donghu High-Tech Zone to become an industrial ecosystem. Parties such as universities and research institutes, venture capital institutions, and business incubators provide a variety of input factors for technology start-ups through the transfer of intellectual property rights or cooperative development. Huazhong University of Science and Technology has placed a large number of graduates into high-tech enterprises. It has also created industrial alliance with multiple companies. Financial institutions supplied vital financial resources, and consulting services for technology enterprises. Incubators help new ventures cultivate talents and absorb scientific and technological achievements and venture capital, hence creating a highly supportive environment to support their growth.

The enterprise communities constitute the core of Donghu. They absorb and transform R&D achievements, talents and funds, and promote transfer of energy and information. The relationship of enterprises is complex and diverse. Some enterprises have close relationships with both upstream and downstream industry, e.g., raw materials suppliers, equipment suppliers, and investment companies. Others have a symbiotic relationship with each other. Finally, competition exists among many companies.

To mitigate risks, and accelerate conversion of new technologies, intermediaries provide professional services to help enterprises. Industry associations establish information and cooperation platforms, and develop industry standards. They can then promote the flow of knowledge and innovation within the industry (Wang et al., 2017).

Government and other environmental factors create a favorable infrastructure for the development of Donghu High-Tech Zone. Convenient transportation, beautiful environment, adjacency to universities and qualified talents are major advantages. Easy access to excellent governmental service facilities in a large city effectively reduces operational costs. To date, Donghu High-Tech Zone has established a culture that is people-oriented in enterprises, innovative and energetic in universities and research institutes, and service-oriented in government. This supportive culture is a major driving force in the evolution of the ecosystem in Donghu High-Tech Zone.

4. Simulation study

We performed a simulation study to assess the effects as described above. System dynamics are often used to simulate a high-order, nonlinear, and complex system such as society, economy, or ecology. The system of Wuhan Donghu High-Tech Zone is composed of multiple innovation bodies and elements that are complex and nonlinear. We constructed the simulation model based on the system structure flow diagram of Wuhan Donghu High-Tech Zone (Fig. 5). The original data in the structure flow chart is obtained from the "Wuhan Donghu High-Tech Zone Statistical Yearbook" and questionnaires we distributed. We used the EViews6 software to process the relationship of variables in simulation.

4.1. Simulation model and loops

The simulation model contains three loops. Loop 1 is about market requirements. There is a need of innovation in the market. Incomes from enterprises, universities and research institutes trigger innovation activities. They will invest more capital and personnel for innovation. The number of patient applications and new products sales revenue will increase. This increase further stimulates market demand for innovation. Loop 1 mainly assesses the interaction effect between innovation and entrepreneurship in Wuhan Donghu High-Tech Zone.

Loop 2 looks at the synergistic effect between technology and system innovation in Donghu High-Tech Zone. An improvement of the innovation level and requirements of regional economic development stimulate the government to pursue a policy for more innovations. Such a policy leads to more financial input in forms such as loans. This leads to an increase of talents and subsequently, an increase of the number of patent applications and new product sales revenue, which eventually raises the government's revenue (tax) and regional economic development level.

In loop 3, the incubation effect is assessed. An increase in innovation level promotes a construction of science and technology business incubators, leading to an enhanced incubation of innovative technologies and products. Similar to loop 3, an enhanced incubation increases the number of patent applications and new product sales revenue, and ultimately improves the total revenue and innovation level of Donghu High-Tech Zonea.

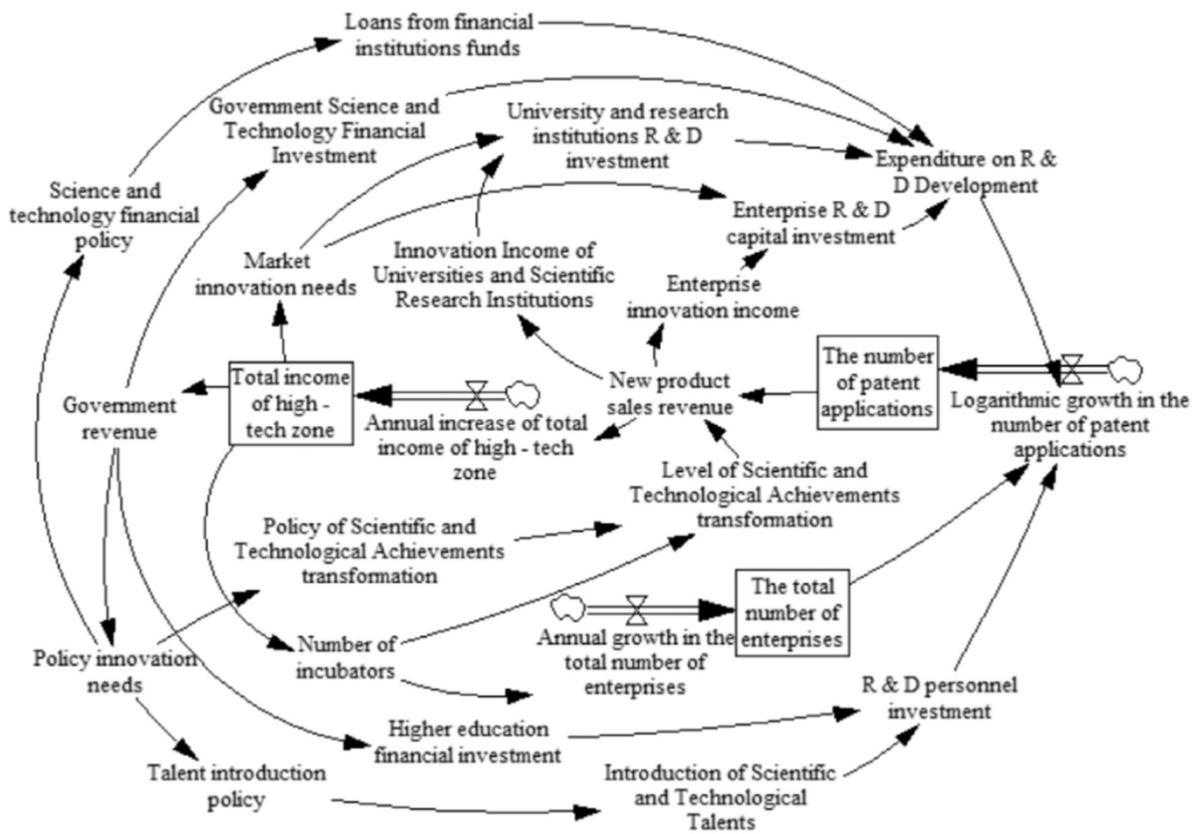


Fig. 5. The simulation model.

4.2. Output variables and model assessment

Scholars have used multiple measures to assess innovative performance. Santoro (2000) used the number of papers produced, the number of patents produced, and the number of new products and processes produced in the collaboration of industry, university and research institution. Zahra and George (2002) used the number of patents, the number of new products, the number of new products and net profit margin to evaluate the cooperation performance. Liu et al. (2011) developed a system dynamics model to analyze the formation of national innovation capacity, and used the number of domestic invention patent applications as output variables.

In this study, we used a system dynamics model to simulate the scientific and technological entrepreneurial effect of Wuhan Donghu High-Tech Zone. We can then analyze the relationship between technological innovation, institutional innovation, technological innovation, and entrepreneurial culture. We used the number of patent applications, total income of high-tech zone and total number of enterprises as output values. The total number of patent applications and the total number of enterprises are direct outputs of scientific and technological innovation, reflecting the level of technological innovation in Donghu High-Tech Zone. Total income of Donghu reflects the economic development level.

We compared the error rate of the simulation model to historical data of the real system to verify the applicability of the model. Fitting results show that the fitting degree of total income of Donghu is 0.9 or more, and the fitting degree of total number of enterprises and patent applications are above 0.8 and 0.7, respectively. These high fitting degrees indicate that the system dynamics model is reasonable and effective, reflecting the operations of Wuhan Donghu High-Tech Zone.

4.3. Simulation results

"Policy laboratory" is an important function of system dynamics. We adjusted policy innovation needs, R&D expenditure and number of incubators in 2006 to observe the effect on three output variables (Fig. 6).

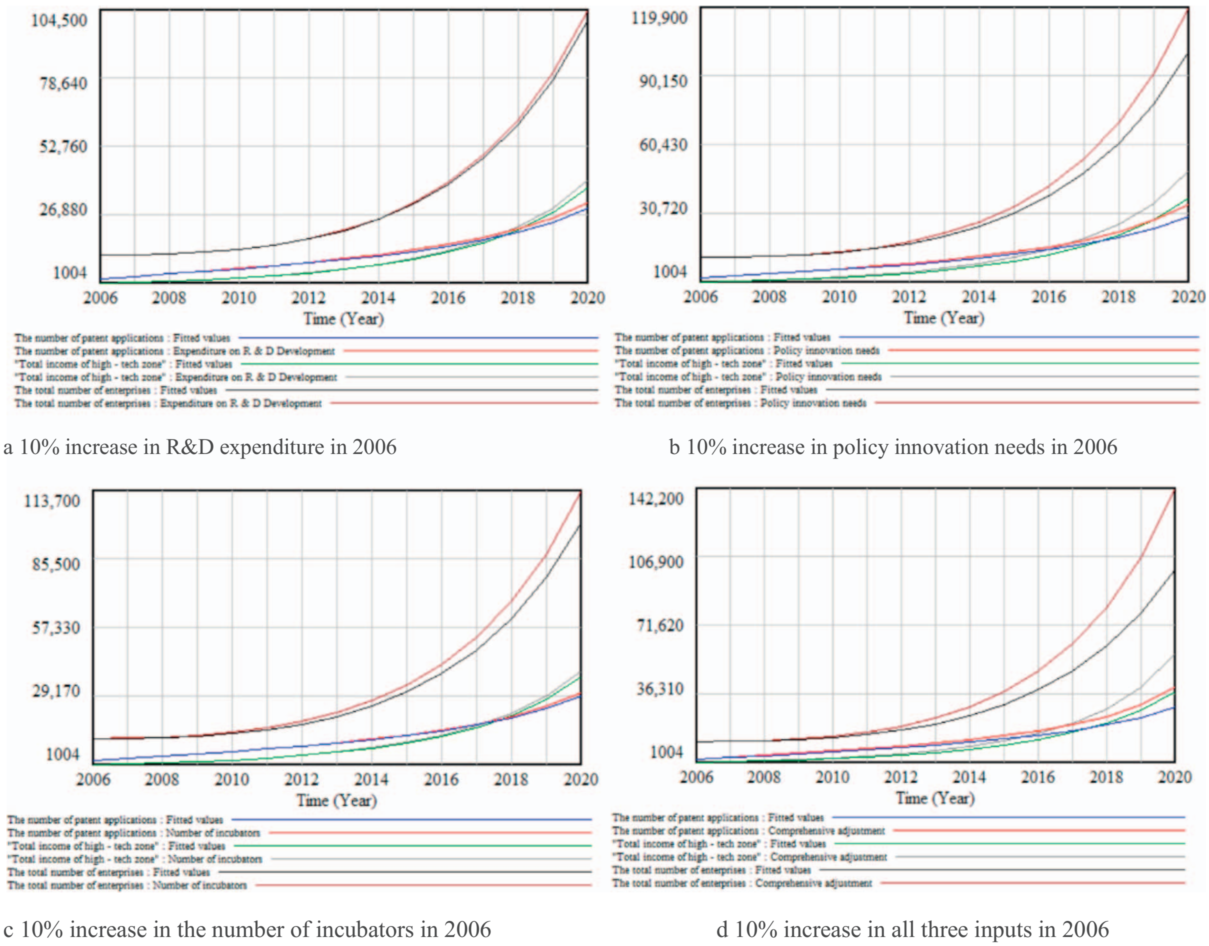
Simulation results show that the impact of a single innovation input on innovation output is small. When R&D expenditure increases, the number of patent applications, the total income of Donghu, and the total number of enterprises have almost no significant changes. But when all three innovation inputs increase at the same time, innovation and technological output and economic output have substantially improved. We interpret it as that Wuhan Donghu High-Tech Zone is an innovative area with multiple innovation entities and multiple innovation elements. Technological innovation, system innovation, technology start-up, and entrepreneurship culture in High-Tech Zone are interrelated and eventually promote technological innovation.

5. Conclusions

5.1. Summary of findings

In this study, we analyzed the effect of several factors on promoting innovation in a science park setting. We compared established and emerging economies to derive the characteristics of science parks. We then proposed a CAER theoretical framework and performed a case study of Wuhan Donghu High-Tech Zone, a famous science park in China. We conducted a simulation study to assess the five effects identified by the model.

Government and market mechanisms play an important role in science parks. Through a promotion of incubators, accelerators, and other entrepreneurial platform, science parks can provide strong support to technology entrepreneurs. There is a strong interaction effect



a 10% increase in R&D expenditure in 2006

b 10% increase in policy innovation needs in 2006

c 10% increase in the number of incubators in 2006

d 10% increase in all three inputs in 2006

Fig. 6. The simulation results.

that science parks can leverage in promoting innovation. Government policies on innovation constantly guide the direction of development and powerfully stimulate the interaction of technological enterprises in the whole science park. As a result, the agglomerations of resources, technology, talents, and enterprises will form an organic ecosystem for innovation and technological entrepreneurship.

5.2. Policy recommendations

Given the simulation results, we have some policy recommendations that will help promote the development of technological entrepreneurship in a science park. First, it is vital to set up carriers for innovation-driven development. Carries should be set up around existing key industries, strategic emerging industries, and future industries. These carriers should be in the forefront of industries with a vision of innovative environment, mature business services, and convenient life. An all-directional system is required to offer services of innovation chain and resources aggregation. Then a significant amount of innovation enterprises will be cultivated to support a sustained high-tech zone.

Policy support is crucial to technological entrepreneurship. The policy systems of "talent + ," composed of talent policies and supporting implementations such as technology finance, mediation services, education spending, can intensify the innovation-driven development in a high-tech zone. It is necessary to have a collaborative mechanism involving government, financial institutions, and high-tech zone management committee to establish technology financial service organizations, such as intellectual property mortgage platforms, or stock deal platforms. In addition, Donghu High-Tech Zone should increase subsidies that contribute to innovation activities in enterprises and innovation-driven development of the high-tech zone.

We also recommend to strengthen a cooperation with international partners. Donghu High-Tech Zone may consider introducing well-known international R&D centers to zone residents. It is a good idea to provide facilities for the settlement and development of such centers.

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