STUDY ON FINANCIAL SUPPORT EFFICIENCY FOR COLLABORATIVE INNOVATION BY LAB-GROWN DIAMOND INDUSTRY CLUSTERS IN CHINA

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ABSTRACT

The use of jewelry and jade and the jade culture has a history of thousands of years in China. They were regarded as exclusive luxuries only available to nobles in ancient times. Luxurious jewelry and jade represented by diamonds have entered the homes of ordinary people since the 1980s as a result of the development of the national economy and the growth of people's income after the continuous implementation of China's reform and opening up. The past studies by Chinese researchers on the diamond industry paid more attention to consumption, processing technology, policy support, and marketing and seldom identified problems in the development of the diamond industry from the perspective of industrial development. Little literature deals with the future demand and development prospects of the diamond industry from the perspective of industry clusters. Moreover, the collaborative innovation activities within industry clusters cannot thrive without financial support. While academia has made some research achievements in this area, a study in depth on the current status and the improvement strategies about the financial efficiency for collaborative innovation by industry clusters has not been conducted yet.

Based on a review of the related literatures and theories about the collaborative innovation by industry clusters and financial support, this study conducts empirical analysis on listed companies of the lab-growth diamond industry cluster in Henan, China, with the DEA model that measures the relative efficiency of input, showing that the efficiency of the sample cluster companies has kept improving in general from 2017 to 2021, and the level of collaborative innovation in the cluster was also increasing. However, there is a large room for improvement in terms of the absolute value of efficiency. A typical example is their pure technical efficiency fell behind the improvement in the scale of efficiency. Accordingly, the dissertation proposes appropriate measures and recommendations aimed at accelerating the improvement of financial service system, which is of practical significance for facilitating the dual progress and development of both the industry clusters and the financial sector. The financial needs of industry clusters are different from those of individual enterprise. To promote effective collaborative innovation in industry clusters, it is necessary to provide innovative and targeted financial service products and enhance the quality of financial services for collaborative innovation in industry clusters with various development stages and development focuses.

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CHAPTER 1

INTRODUCTION

China's diamond industry has a long history. Imperial Diaries of Jin written by Huang Shi during the Jin Dynasty contains the earliest record of diamonds found in the Chinese literature: "Dunhuang sent diamonds in the third year of Xianning (AD 277). It was found among metals and did not disappear after numerous times of washing. It is from Tianzhu and can be used to cut jade." "Tianzhu" is the ancient Chinese name of India. "Nowadays, diamonds are found outside China. They are stones but similar to metals. They are glorious and can be used to carve jade. Foreigners carry them to expel evil spirits and for other similar purposes," mentioned by Guo Pu of the Eastern Jin Dynasty in his notes to The Classic of Mountains and Seas -- "The Classic of Xishan II." The historical book Imperial Diaries of Song Yuanjia written by Pei Songzhi, a historian of the Southern Song Dynasty, records the words and deeds of Emperor Song Wendi in his daily life. The book also mentioned diamonds coming from Tianzhu. "In the fifth year of Wendi, Yueshou, King Pijiali of Tianzhu, sent an envoy, who submitted a diamond ring, an embossed gold ring, a set of bird hair, six sections of white sandalwood, a white parrot, a red parrot, and two fine sheets," says the book. A gold ring inlaid with a diamond was one of the artefacts unearthed from an Eastern Jin tomb in Xiangshan, Nanjing. The diamond's diameter is about 1 millimeter, and the ring's diameter of the ring is 2.2 centimeters. It is the oldest diamond discovered in China by now. The literature and unearthed ancient artifacts suggest that the use of diamonds started in the third century through the fifth century in China, and all of the diamonds came from India. During the Ming Dynasty, Li Shizhen included diamonds as a drug under the category of "metals and stones" in Compendium of Materia Medica. He noted that "Diamond is also known as Jin Gang Zuan. Its grains can be used to drill jade and repair porcelain, so it gets its name of Zuan (meaning drilling)." This explains why diamonds are called Zhuan Shi (meaning drilling stone) in Chinese. Li Shizhen also noted that "Diamond comes from Tianzhu kingdoms to the west of China." This suggests that diamond deposits were hardly found in China, and all the diamonds were imported in the 16th century.

The modern diamond industry started late in China. China's jewelry industry was concentrated in Beijing, Tianjin, Shanghai, and some other big cities, where a few processing and retail of diamonds were found, in the early years of New China. The Chinese government restored the domestic market of gold and jewelry in 1982, shortly after the start of the reform and opening up. The jewelry industry started to develop rapidly but was still limited to the traditional categories of gold, silver, jade, and jadeite. Diamond was little known. De Beers, which controlled the largest supply of diamonds in the world, tested the market in Xiamen, Fujian in the 1990s. After gaining enough confidence in the market, De Beers formally entered the Chinese market in the mid-1990s. It cooperated with China to release China's national diamond rating standard in 1997. It also assisted the national jewelry inspection authority in training jewelers and their employees from major cities in diamond knowledge. After that, a professional and systematic diamond industry started to form in China.

In October 2000, the State Council approved the establishment of the Shanghai Diamond Exchange, which was the first and is now the only diamond import and export trading platform in the Chinese mainland. Later the China Diamond Trading Center was established based on the platform. This move drove the development of China's diamond industry, especially its import and export of diamonds. At the same time, an industry cluster of diamond processing has gradually formed in Guangdong, which houses more than 70% of the diamond and jewelry processed in China. Especially, Panyu of Guangzhou and its surrounding areas have attained high levels in diamond production, technology application, design, and management and enjoyed the reputation of "Chinese workmanship" in the world. The region has formed a diamond industrial base covering international diamond trade, diamond dividing and polishing, rough diamond wholesale, creative design, jewelry inlay, branded retail, and other activities (Zhang Xiongzhi, 2022). The founding of Guangzhou Diamond Trading Center Co., Ltd. in July 2015 with the approval of the Guangdong Provincial Government further drove the strategic cooperation between the upstream and downstream segments and cluster development of the diamond industry in Guangdong. The processing and trading volume of gold, platinum, and diamond in Guangdong accounted for 80%–90% of the annual trading volume of the Shanghai Gold Exchange and the Shanghai Diamond Exchange in 2019. The diamond industry has a relatively complete and professional industrial chain and industry cluster in Guangdong compared with other regions in China.

The raw diamond mining volume of De Beers, the world's largest mining company, has dropped from two-thirds to 30% of the industry's total in the past 30 years. The supply of mined diamonds has been dropping by about 1.5% every year. As a result, the imbalance between supply and demand in the world diamond market has become increasingly conspicuous. Lab-grown diamonds slowly entered the commercial market since the start of the new millennium in China. From 2000 to 2014, the products on the market were mainly small and medium-sized (smaller than 0.1 carats) lab-grown diamonds in addition to small quantities of yellow, blue, and other colored lab-grown diamonds of larger sizes, which are sold as research products to certain buyers. At that time, lab-grown diamonds were still in the marginal zone compared with the whole jewelry market, and mainstream players paid little attention to them. The business of lab-grown diamonds only generated petty profits.

Lab-grown diamonds proved that they deserved attention in 2015 when the Hong Kong Lab of International Gemological Institute (IGI), an international gem testing organization, certified the world's largest colorless HPHT lab-grown diamond. It weighed 10.02 carats and was made from a raw lab-grown diamond with a record weight of 32.26 carats in no more than 300 hours. This suggested that lab-grown diamonds were no longer substitutes for small diamonds to complement larger ones. They were about to perform as leading actors. The Federal Trade Commission (FTC) of the United States revised the definition of diamond by removing the qualifying term of "natural" in 2018. This meant that lab-grown diamonds were formally included in the diamond category and distinguished from synthetic diamonds as an industrial product in the future trade administration.

This study focuses on the following two questions:

The first is about the evaluation of methodology and efficiency of financial support for collaborative innovation in industry clusters. Finance plays a crucial role in the collaborative innovation system of industry clusters. On the one hand, financial institutions operating within a specific institutional framework provide start-up and operational funds for innovation within industry clusters as well as financial support and services for key industries identified in national strategic plans. Such financial support helps in steering the economic structure and social capital targets of industry clusters. On a macro level, it drives market structure optimization and adjustment and improves innovation capabilities and competitiveness of industry clusters and regions through the accumulation of funds. On the other hand, the performance of collaborative innovation in industry clusters is heavily influenced by the efficiency of financial support. Effective financial support is a crucial precondition for sustainable development and industrial upgrading of industry clusters. The collaborative innovation system of industry clusters operates under a unique mechanism that demands unprecedented channels, structures, models, and other aspects of financial services. As a result, innovation in the financial sector can benefit significantly from innovation in industry clusters. However, the reality is that effective financial support is often missing for the behavior of collaborative innovation in industry clusters due to financial exclusion, financing constraints, and other adverse factors. Enhancing the effectiveness of financial support for collaborative innovation in industry clusters is a pressing issue for promoting regional economic development.

The second is about the mechanisms and efficiency of financial support in promoting collaborative innovation in lab-grown diamond industry clusters in China. The theoretical research and development of regional competitiveness show that the competitive advantages of a country or region come from the advantages obtained in the process of industries agglomerating within the country or region. In the global market, the global raw diamond production exceeded 136 million carats in 2013. Researchers predict that the raw diamond production will gradually decrease in the next decade. The production may begin to decline after 2025 as some mines plan to cease operation. The diamond industry faces uncertainties and challenges brought about by the increase in mining costs, the trend of branded consumption, and the development of lab-grown diamond technology. Currently, China is the fifth largest importer of rough diamonds, the second largest consumer of finished diamonds and diamond jewelry, and an important diamond manufacturing center in the world. China's diamond industry has developed rapidly in the past few decades with remarkable achievements. However, it is beset by problems such as deficiencies in the industrial chain, blindness in development planning, lack of product differentiation, and insufficient technological innovation, and it faces the ever-changing market environment and various challenges in the future. China accounts for 42.9% of the global production of lab-grown diamonds from the perspective of industrial chain structure. It has a large room for expansion in terms of technology research and development, diamond processing, and market demand for lab-grown diamonds. Currently, China's production of lab-grown diamond is mainly concentrated in Zhengzhou, Nanyang, and some other places in Henan Province, where a diamond industry cluster has taken shape integrating research and development, large-scale production, and sales of lab-grown diamond products.

The main composition of this study is described as follows:

(1) This dissertation uses the theory related to industrial clusters to explain and analyze the connotation and methods of financial support for collaborative innovation in industrial clusters.

(2) This dissertation examines the efficiency of financial support for promoting collaborative innovation in diamond industry clusters and applies the DEA (data envelopment analysis) model introduced by Charnes, Cooper, and Rhodes for empirical analysis. The sample consists of seven representative listed companies from the lab-grown diamond industry cluster in Henan, China, namely North Industries Red Arrow, SINOMACH Precision Industry, CHJ Jewellery, SF Diamond, Jingsheng Mechanical & Electrical (JSG), Yuyuan and Huifeng Diamond.

Based on empirical analysis, the dissertation concludes that the efficiency of the sample cluster companies has kept improving in general from 2017 to 2021, and the level of collaborative innovation in the cluster was also increasing. However, there is a large room for improvement in terms of the absolute value of efficiency, a typical example of which is their pure technical efficiency fell behind the improvement in the scale of efficiency.

CHAPTER 2

LITERATURE REVIEW

The diamond industry is an industrial chain formed and developed around diamonds. An industrial chain extends in four dimensions, i.e., value chain, space chain, supply and demand chain, and enterprise chain. These dimensions interact with each other to achieve equilibrium while the industrial chain develops. The diamond industry's industrial chain consists of seven links (Figure 1-1), among which raw diamond mining and trading are in the upstream sector, dividing and polishing, and raw diamond wholesale are in the midstream sector, and diamond design, processing, and retail are in the downstream sector (Du Wei, 2016). The types and characteristics of the jewelry industry in different regions differ depending on the general conditions, environment, influencing factors, and resource dependence in these regions as well as the interaction between the characteristics of market structure.

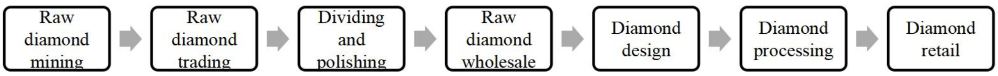

Figure 1 Seven Links of Diamond Industry Chain

To enhance competitiveness and size greater market shares, enterprises at these links of the diamond industry would choose to cooperate with other enterprises or institutions to complement their own strength. Networks of geographical and spatial ties have gradually taken shape to produce synergy through interactions in terms of production, talent, technology, design, innovation, and other fields. This further deepens and strengthens the competing and cooperating relationship between the jewelry industry and related industries and institutions in a certain region. Diamond industry clusters have gradually formed with the participation of more enterprises in the same region. In general, a diamond industry cluster is a group agglomerating diamond enterprises as the core, which drives related industries, related and supporting institutions, related decision-making authorities, and supporting facilities to gather and develop synergy in a certain geographical location, and there are close economic and social capital connections among them.

1. Existing Literature on Diamond Industry Clusters outside China

In other countries, studies on the diamond industry began around the 1940s. Oxford University Press reprinted "Diamond Industry in Wartime, 1941," an article originally appeared in *The South African Mining and Engineering Journal*, in *The Royal African Society* in 1943. The article described the production and trade of diamonds in the world in 1941. At that time, the world's upstream sector of diamonds was concentrated in Africa, followed by North America and Brazil, while the processing and sales of diamonds were mainly based in European countries, especially Low Countries such as Britain and the Netherlands. Antwerp of the Netherlands was then a world-famous center of diamond processing.

Several diamond processing and trade centers emerged in the 1970s, along with changes in the world political and economic landscape and the recovery and development of industries around the world. Israel was a remarkable example among them. Therefore, academia began to study these cities or regions with industrial centers, especially Israel. For example, David Levhari and Eytan Sheshinski jointly wrote "Experience and Productivity in the Israel Diamond Industry" in 1973, which analyzed the operating mechanism, organizational structure, and technological innovation of Israel's diamond industry to sum up advanced experience replicable in other regions (David Levhari and Eytan Sheshinski, 1973). Their thinking showed obvious awareness of concepts such as "industrial district," "industrial space," and even "agglomeration" and "clustering," which were probably influenced by the enthusiasm for research on national competitiveness and regional economies at that time. To some extent, their studies can be regarded as early efforts of research on diamond industry clusters in the world.

The research on the diamond industry started to cover more diverse and extensive fields after that. The academic research on the diamond industry focused more on Africa and the legalization of the industry, protection of laborers' rights and interests, etc. in the region from the 1990s to the beginning of the new century because of serious issues and controversies encompassing "blood diamond." For example, "Sierra Leone: The Political Economy of Civil War, 1991-98" elaborated on the important role played by the diamond industry in this turbulent African country (Zack and Alfred, 1999). The mining of natural diamonds may inflict a significant environmental damage on the Earth, and research by Anile Kumar et al (2021) suggests that the issues in the mining of natural diamonds, such as the 'blood diamonds' and the child labor, are increasingly arousing discomfort among young people about buy natural diamonds. Since 2010, the international research on diamond industry clusters has further expanded to the industrial chain's globalization and humanization (Tusalem, Rollin, and Minion, 2014), sustainability (Calvao, Filipe, and Victoria Gronwald, 2019), international responsibilities and obligations (Bieri, Franziska, and John Boli, 2011), etc. Their studies have provided important inspiration for related studies by Chinese researchers.

According to Lennings C. J. (2010), the relationships between the suppliers of raw materials, processors and sellers of diamond products are generally loose in the circulation of Chinese diamond products, and the enterprises mainly engage in competition and short-term cooperation against multilateral cooperation, leading to a win-win situation for all parties involved. To some extent, the green supply chain in diamond industry breaks the boundaries between enterprises, achieving an integrated management of logistics, information flows and capital flows of all enterprises upstream and downstream along the whole supply chain, which enables the collaborative operation and win-win cooperation between all links in supply chain, as well as a long-term and stable strategic partnership.

In the wider realm of jewelry industry, Jose Luis and Jose Albors (2009), through semi-structed interviews with 57 enterprises within the ceramics industry cluster in the Romaga region, suggest that the formation of resource-dependent industry clusters is influenced by the extent of industrial development, and the key factors in the formation of resource-dependent industry clusters include mechanisms of knowledge spillover, government guidance and economies of scale. Lisa De Propris and Ping Wei (2007), in their article *Creativity and Space: The Opportunity of* *an Urban Creative Jewellery Cluster*, identify market demands, creativity and network relationships of clusters as the driving forces behind the formation of the Birmingham jewelry cluster, and creative capacity and creative designs as major drive forces propelling the Birmingham jewelry cluster to the high-end market. Based on the data in terms of creative capacity for internal and external design of enterprises, government policies, industry chains and related industries, Lisa De Propris and Ping Wei, through empirical analysis in four dimensions of Birmingham, the West Midlands, the country and the world, suggest that policy plays a critical role in the vitality of industry clusters. Analysis on governance structure within the Jewellery Quarter reveals that the governance of jewelry cluster in Birmingham is characterized by interdependence, with a lack of one or several large leading enterprises driving regional activities due to the decentralized decision-making authority. However, the level of connections and cooperations between the enterprises is insufficient to foster a sense of belonging to cluster, and enterprises are reluctant to join any local or national trade organizations. Therefore, the article concludes in suggesting that the parties involved should be encouraged to engage in the formulation of a new agenda for the Birmingham Jewellery Creative Quarter, and that some of the regeneration agencies should be stimulated to integrating jewelry industry with creative culture industry through the formulation of management, governance and institution systems at both the enterprise and cluster level, to enhance the overall competition of Birmingham jewelry industry cluster.

Bagnasco, Bacattini and other Italian scholars have concluded from their research on the Third Italy industrial zone that the development of industry clusters is attributed to the economic externalities realized regionally based on a high degree of labor division and mutual collaborative partnerships among the enterprises supported by the local social and cultural backgrounds. American scholars Piore and Sabel (1984) have argued, in their book *The Second Industrial Divide*, that the formation and development of industry clusters relies on the concentration of a large number of small and medium-sized enterprises with Flexible Specialization.

The United Nations Conference on Trade and Development (UNCTAD, 1998) classifies clusters into two types: spontaneously formed clusters and artificially formed clusters, which to some extent reflects the formation mechanism of industry clusters. Henry G. Overman, Stephen Redding and Anthony J. Venables (2001) delved into the factors determining trade costs and the influence of the costs on trade flow from the perspective of economic geography theories, and analyzed the formation and development mechanisms of industry clusters based on the research on geographical trade flow and the effect of factor prices. According to Camison (2004), the formation of industry cluster in a certain region is dependent on the locational comparative advantage, resources sharing advantage and the ensuing competitive advantage. Boschma and Frenken (2006) argue that the formation and development of industry clusters primarily depends on the perpetual cycle and accumulation of economic externalities, with cluster advantages extending to associated industries through the agglomeration of economic benefits.

2. Existing Literature on Diamond Industry Clusters in China

The research on industry clusters in China began at the end of the 1990s, almost the same time as that of international academia. In 2000, Li Jianjun received a doctoral degree from Renmin University of China with a dissertation entitled "Silicon Valley Model and Its Industry-University Innovation System," which was the earliest academic study in China to systematically analyze the examples of industry clusters. Industry clustering has been a hot topic of economics research in China since then. CNKI alone has indexed 88,000 related pieces of literature, including 51,500 journal papers and 15,200 master's and doctoral dissertations. The research in this field reached its climax with 7,588 papers published in 2010. Though the attention to this field has decreased since that, it is still a hot topic of economic research, as 5,083 new studies were published in 2021.

Currently, most of the existing studies in China on industry clusters focused on various existing industries. They conducted model analysis and theoretical development in the contemporary context of the Internet and digitization. These studies involved a wide range of industries, including agriculture, forestry, tea, and other fields of agriculture and forestry; traditional industries such as leather products, paper, automobiles, and clothing; emerging industries such as tourism, logistics, e-commerce, sports, and cultural industries; high-tech industries such as biomedicine and maritime industries. Examples include "International Experience and Inspiration of Development of Strategic Emerging Marine Industry Clusters -- An Analysis Framework Based on Dynamic Mechanism of Industry Clusters" (Wu Chunmeng and

Bai Fuchen, 2022), "Study on Competitive Advantage of Leather Industry Cluster Ecosystem against Background of "Internet+" (Liu Jiang, 2022), and "Digital Governance of Industry Clusters: A Theoretical Framework "(Qi Yu and Liu Hanmin, 2022). There are also more innovative studies on the regional brand building of industry clusters and other topics. Rather than focusing on specific industries, they conducted theoretical explorations from the perspective of the clustering model, such as "Study on Regional Brand Building of Industry Clusters in the New Era -- Taking Wuxi as an Example" (Fan Hanjue, 2021).

However, there is a dearth of research on China's diamond industry. 77 master's and doctoral dissertations on diamond written from 2020 to 2022 have been reviewed. 38 of them studied industry clusters based on Michael Porter's Diamond Model, involving segments such as Chinese wolfberry, beef and mutton, international hotel management, dairy, health, sport event and exhibition, water sports, and ski tourism. Among the 20 pieces focusing on real diamond, 12 are about the research of gemology and physics on diamond dividing, synthesis, and testing. Two are about diamond jewelry design. One is about the linguistic research on the translation of diamond-related news. Two are about the management research on diamond marketing strategy. Two are about the financial research on investment in diamond and tax-related issues in diamond transactions. Only one is about the diamond market, i.e., "Economic Transformation and Development in Botswana (1980-1998)" by Chang Junshan, a master's degree receiver of Shanghai Normal University in 2021. Botswana is an African country that has developed rapidly by relying on diamond resources. The dissertation gives a comprehensive analysis and discussion of Botswana's diamond industry, which plays an important role in the country's economic transformation and development as a pillar industry. A noticeable gap is seen in the Chinese literature on the diamond industry, especially that on China's own diamond industry.

The specific research by Chinese researchers in connection with China's diamond industry is thought to begin in October 2000, when China's first diamond exchange was established in Shanghai. In the same year, Ma Tingting and Zhou Zuyi of the Gemology Education Center of Tongji University published the paper entitled "Development of Global Diamond Processing and Trade Center and Its Inspiration to China's Diamond Industry." They summarized the successful experience of the world's four major diamond processing and trade centers, i.e., Antwerp, Israel, New York, and India. They tried to apply their findings to China's diamond industry, which was still in a barbaric growth stage at that time. The paper was an early systematic academic study in China on China's diamond industry. The 2003 Shanghai International Diamond Summit held focused on the development strategy of China's diamond industry. People's Daily published the report entitled "Processing Technology, Policy Environment, and Market Demand: Three Favorable Factors for Diamond Industry" in 2004. It observed that "nowadays, China's diamond processing industry has attained a large scale, and is concentrated in Panyu and Conghua of Guangdong, Shanghai, and Qingdao, with increasing advantages of agglomeration. The processing enterprises in a cluster share resources and complement each other, forming a virtuous environment of joint development" (Dai Lan, 2004). This was the first official report explicitly related to the diamond industry clusters in China. About five to seven reports on the diamond industry appeared every year after that. Examples include "Constraints Encountered in Further Expansion of Conghua Diamond Base" (China Gold News, 2005), "When Will Shanghai Become a Capital of Diamond" (Shanghai & Hong Kong Economy, 2005), "Jewelry Industrial Park Proposed for Dongguan" (China Mining News, 2006), "China Enters Upstream Industrial Chain of Diamond" (China Business Times, 2006), "China Builds a Complete Global Diamond Industrial Chain" (International Business Daily, 2006), and "Guangzhou Conghua's Diamond Export Grows by 20% per Year: to Build a Jewelry Industry Base and Lingnan Jewelry City" (China Gold News, 2007). These reports analyzed the industrial chain, industrial districts, and industry clusters of diamond to various extents, but none of them dealt with them from academic perspectives. Lin Zheying, then deputy director of the Foreign Investment Department of the Ministry of Commerce, published the paper entitled "Development Status and Prospects of China's Diamond Industry" in 2008. The paper scientifically analyzed the development status, prospects, and external environment advantages of China's diamond industry and took a very positive attitude toward the whole industry's future. According to the paper, "The Shanghai Diamond Trading Center has the full potential to become a diamond resource allocation center covering the whole Southeast Asia... strive to transform the current diamond trading and logistics platform into a complex integrating trading, processing, sales, appraisal, exhibition, training and other functions covering a longer diamond industrial chain as soon as possible to improve the general international competitiveness of China's diamond industry" (Lin Zheying, 2008). The paper recognized the importance and necessity of clustering from the national policy perspective. The industrial chain development became a priority of China's diamond industry after that, as discussed in "Establishing Jewelry Brands through Industrial Chain Cooperation" (China Gold News, 2009).

The global diamond industry, however, suffered a downturn due to the impact of the international financial crisis in 2008. Related research almost stalled ("Diamond Industry in the Slow Global Economy Recovery," Shanghai Diamond Trading Joint Management Office, 2010). In 2012, Guo Shenghai obtained a master's degree in business administration from China University of Geosciences with the dissertation entitled "Study on Diamond Consumption Structure and Influencing Factors in China," which was the first degree dissertation of systematic research on the diamond industry, market, and consumption structure in China. The third chapter of the dissertation, "Analysis of China's Diamond Industry," examines the evolution, environment, and issues of China's diamond industry from the perspective of industrial development status and the perspective of marketing strategy. However, the author focused more on the analysis of the diamond industry from the perspectives of the market, sales, and consumption without dealing with the production, industrial chain, and even industry clustering of diamond in detail. In the same year, Zhou Ying, a design art major from the same university, wrote a master's degree dissertation entitled "Analysis of China's Color Diamond Market." The dissertation analyzed the color diamond segment, which was rarely studied at that time, from the perspective of jewelry marketing. The second chapter of the dissertation summarized the formation, development, advantages, and causes of China's diamond market. In 2014, "Exploration of Botswana's Experience in Economic Development" (Wei Yu, 2014) and the master's dissertation "Evaluation of Green Supply Chain in Diamond Industry" (Yaya, 2014) focused on the diamond industry in African countries and provided valuable information for China. "Analysis of Diamond Consumption Market and Study on Its Financial Attributes," an MBA degree dissertation submitted to Shanghai Jiaotong University in 2015, analyzed the global and Chinese diamond consumption and consumption characteristics, tried to find solutions for problems existing in China's diamond industry, and helped ascertain the development direction of the diamond industry by studying the financial attributes of diamond. In 2016, researchers from the Gem and Jade Research and Appraisal Center of Sun Yat-sen University and the Guangzhou Diamond Exchange published "Dilemma and Challenges Faced by International Diamond Industry in 2015", which analyzed in detail the immense turbulence in the international diamond industry since the second half of 2014 and gave some recommendations. The paper carefully analyzed the data of the diamond industry chain and suggested that diamond dividing and polishing firms should reconsider their scale of business and development mode... In the future, the cooperation between the midstream segments and downstream ones may pave an important way for the diamond industry to cope with rising prices of rough diamonds and increasing challenges in the retail market. A new round of consolidation became imperative obviously in the diamond industrial chain (Liu Lu, Qiu Zhili, Liang Weizhang, et al., 2016). The so-called "industrial chain consolidation" is very close to the concepts of industry cluster and clustering. In 2017, Song Jiandan's master's degree dissertation "Geographical Perspective on the Evolution of Temporal and Spatial Pattern of World Diamond Industry" reviewed the evolution of the diamond industry chain in detail and analyzed the development of China's diamond industry with the SWOT model, which provided valuable information for the research on diamond industry clustering. Hubei Exin Diamond Technology Co., Ltd. published the paper entitled "Status quo and Trend of Diamond Used in Jewelry" in 2018. It analyzed the global and domestic consumption and industrial distribution of lab-grown diamonds and diamonds used in jewelry. It had a part related to the diamond industry, which mainly analyzed the technology, equipment, and production capacity characteristics of lab-grown diamonds and did not deal with industrial chains and industry clusters. "Study on Dilemma in Development of Industry Chain for Platinum Jewelry Inlaid with Diamond in China" was a master's degree dissertation submitted by Fang Hua to the University of International Business and Economics in 2019. Focusing on a specific category of products in the diamond industry, the dissertation analyzed the industrial chain in detail. However, it did not cover the front end of jewelry, i.e., the mining, dividing and polishing, processing, and other production activities of raw diamonds. The dissertation concentrated on the downstream industrial chain with jewelry producers, retailers, and end consumers.

Being an important emerging characteristic industry in Guangdong Province, the jewelry and jade industry manifested a trend of cluster development in the province in 2019. Currently, Guangdong has eight areas with concentrated enterprises engaged in the gem industry in Guangzhou, Shenzhen, Sihui, Pingzhou, Panyu, Huadu, Jieyang, and Ketang as industry clusters. Compared with other regions in China, the jewelry and jade industry in Guangdong has a relatively complete industrial chain from raw material procurement to R&D and design, production and processing, and wholesale and retail. Zhang Xiongzhi, chairman of the Guangzhou Diamond Exchange, published the paper entitled "Analysis of Development Status of China's Diamond Industry and Recommendations on High-quality Development Strategies" in 2022. It has been the latest domestic academic study on China's diamond industry. The paper analyzed the status quo and industrial chain of the diamond industry with the SWOT model and called on the domestic diamond industry, especially that in Guangdong, to extend the industrial chain and realize smooth re-allocation of resources from upstream to downstream segments. In fact, it also emphasized industry clustering as the direction of development. To sum up, the studies by Chinese researchers on the economics and management of China's diamond industry mostly focus on marketing and lack attention to the diamond industry chain, industrial agglomeration, and industry clusters. Moreover, industry clusters are still considered a focus and difficulty of academic research at present against the background of building the Greater Bay Area and the national policies for industrial revitalization. Therefore, it is necessary and possible to explore the status quo of China's diamond industry from the perspective of industry clusters and identify the direction for the future development strategy.

CHAPTER 3

RELATED CONCEPTS AND THEORETICAL BASIS

Michael E. Porter, a professor at Harvard Business School in the United States, introduced a new concept of "industry cluster" by applying the ecological concept of "cluster" to economics in his book *The Competitive Advantage of Nations* published in 1990. Chinese and foreign researchers have continuously studied and expanded the concept in depth ever since.

Michael Porter explained why he used the term "cluster" in economics in the notes to a reprint of *The Competitive Advantage of Nations*. A cluster refers to a group of interrelated companies, suppliers, relevant industries, and specialized institutions and associations engaged in a certain field in a specific region. Before that, economic geography and regional scientific literature had long recognized the existence of business clustering, but researchers only conceived clusters in a relatively narrow sense and did not associate this phenomenon with the growth of international competitiveness. Clusters can not only reduce transaction costs and improve efficiency but also improve incentives and create collective assets such as information, professional systems, and reputation. More importantly, clusters can improve the conditions for innovation, accelerate the growth of productivity, and facilitate the formation of new enterprises.

1. Lab-grown Diamond: Development of Man-made Diamonds

Lab-grown diamonds have the same integrity of crystal structure, transparency, refractive index, dispersion, and other properties as those of natural diamonds and are considered genuine diamonds. Natural diamonds have formed in carbon layers deep underground, where graphite carbon is compressed to develop the diamond structure under ultra-high temperature and high pressure. Lab-grown diamonds are grown in labs. Natural or man-made diamonds are used as seeds to coat diamond layers, simulating the growth environment in which natural diamonds grow. The seeds grow slowly into larger diamonds in the lab environment. The relationship between natural diamonds and lab-grown diamonds is like that between ice in rivers and ice in refrigerators, as they share the same composition and appearance: Both natural diamonds and lab-grown diamonds are crystals made of pure carbon, and they have identical crystal structures as well as physical, chemical, and optical properties. Zircon (cubic zirconia), mossanite (silicon carbide), and other similar minerals are quite different from diamonds in physical properties and chemical composition, so they are considered diamond alternatives.

In 1955, GE of the United States announced that it had successfully created a diamond with a hydrostatic melt medium method (GE method). In 1970, GE made carat-grade (larger than 5 mm) gem-grade diamonds with the GE method. In 2015, the International Organization for Standardization (ISO) clarified that synthetic diamond and lab-grown diamond were synonymous. In 2016, the International Grown Diamond Association (IGDA) was established. In 2018, the US Federal Trade

Commission (FTC) included lab-grown diamonds in the category of diamond. In March 2019, the American Gemological Institute (GIA) updated the terms on lab-grown diamond certificates. In 2020, GIA started to issue new digital lab-grown diamond grading reports. In March 2021, China's National Gemstone Testing Center (NGTC) started to issue a special testing certificate for lab-grown diamonds. Currently, the three major authoritative international jewelry appraisal institutions, i.e., American Gemological Institute (GIA), International Gemological Institute (IGI), and Belgian Diamond High Council (HRD), all provide appraisal services for lab-grown diamonds according to the internationally recognized 4C standard, which is the same as that for natural diamonds.

According to a report released by Bain & Company, the diamond consumption market has been stable in the past decade except for 2020. In the year, the global sales of diamond jewelry declined to USD 68 billion due to the Covid-19 pandemic in 2020. The sales rebounded to USD 84 billion in 2021, an increase of 23.5% year-on-year. The compound growth rate of the global production of lab-grown diamonds exceeded 120% from 2017 to 2019. The global production of lab-grown diamonds reached 7.2 million carats in 2020, while the global production of natural diamonds reached 113 million carats. The penetration rate of lab-grown diamonds increased to 6% in 2020 and is expected to increase to 7.2% in 2021. In 2020, the total retail sales of diamond jewelry reached USD 68 billion, including lab-grown diamond jewelry worth USD 1.65 billion. The penetration rate of lab-grown diamonds by production value was about 2.4% in the year. In 2021, the total retail sales of diamond jewelry reached USD 84 billion, including lab-grown diamond jewelry worth USD 4.4 billion. The penetration rate of lab-grown diamonds by production value increased to 5.2%.

2. Concepts and Characteristics of Industry Cluster

An industry cluster refers to a number of enterprises and institutions, related and supporting organizations and groups that come geographically close to each other through contact and interaction. They create an atmosphere of mutual trust, exchanges, and cooperation, promote management innovation, especially technological innovation, resulting in industrial ties and mutual influence as well as external economies and cost reduction, overcome or build market barriers, and thus accelerate the formation of a relatively stable, open and flexible network (Chen Guanming, 2020). An industry cluster is not a simple gathering of enterprises or institutions. It involves related enterprises (including chambers of commerce, associations, banks, intermediaries, etc.), clear industrial themes (specific enterprises), stable network characteristics (social networks), and competitive organizational forms.

Industry clusters can be divided into Marshall industry clusters, axle-type industry clusters, satellite-type industry clusters, and government-positioned industry clusters by the structure of industrial districts. They can be divided into pure agglomerations, industrial communities, and social networks from the perspective of transaction costs. Industry clusters can be divided into standard (modular) industry clusters, associated industry clusters, and captive (controlled) industry clusters from the perspective of the governance structure of the value chain. Industry clusters can also be divided into native industry clusters (such as specialized industrial districts in Zhejiang), embedded industry clusters (such as export-oriented industry clusters in Guangdong), and derivative industry clusters (such as the Zhongguancun Industry Cluster and industry clusters derived from state-owned enterprises) (Jia Yingying, 2016).

Industry clusters are generally characterized by networking, concentration, homogeneity, relevance, embeddedness, and other structural features. Networking refers to the formation of a relatively stable relationship between upstream and downstream enterprises and related and supporting industries within the cluster with specialized division of labor. The cluster features strong self-organization and self-enhancement effects, and enterprises of different sizes are matched with each other based on their capability of production technology, management, funding, marketing, trade, etc., thus forming a highly decomposed flexible organizational structure. Cluster networking promotes the dissemination of knowledge, so it has a strong ability for learning and innovation. Concentration can be understood as "geographical proximity," which means the enterprises, institutions, platforms, and other industrial entities within the cluster are relatively concentrated, produce an effect of scale, and promote communication, learning, and cooperation within the cluster. From the perspectives of homogeneity and relevance, the main business within the industry cluster is highly consistent, and the enterprises are engaged in the same or similar economic activities or business lines highly related to the main business or being upstream or downstream of the main business. An industry cluster is usually a community jointly created and supported by the government, enterprises, universities, and scientific research institutes. In this respect, embeddedness is reflected in not only the relational embedding of enterprises in the cluster network but also the structural embedding of enterprises in the local culture, systems, infrastructure, etc. These factors determine the local embeddedness of the cluster.

Industry clusters have five competitive advantages in spatial agglomeration, market, dynamics, systems, and technology. The advantage in spatial agglomeration refers to the fact that the industry cluster has been formed spatially, generating advantages in terms of cost, resources, and external economy. The market advantage refers to the economic network relationship established against the background of a common industrial culture to retain existing customers, attract new customers and producers, and reduce transaction costs. The advantage in dynamics refers to the competitive advantage attained by the industry cluster from internal interaction, learning, and knowledge innovation. The advantage in systems refers to the industry cluster's status as an intermediate body between enterprises and the market, so they can have unique advantageous systems. The advantage in technology refers to the fact that the industry cluster is able to promote the innovation and dissemination of knowledge and technology, and finally realize innovation in industries and products and differentiated development.

3. Development Process of Industry Clusters

The trend of clustering began to appear at the end of the 18th century after the industrial revolution. This trend became more conspicuous in the next one or two centuries. During this period, transportation conditions and communication technology were the main factors restricting the geographical distribution of industries, and natural resources or market locations were the main reasons restricting the site selection of production activities and the agglomeration of industrial activities to specific locations (Sun Jiuwen, 2020). Examples of this period included Chicago, Pittsburgh, and Boston in the northeast of the United States; Liverpool, Manchester, and Edinburgh in Britain; areas along the Rhine River and Ruhr in Germany. These cities or regions were located by coasts or along rivers with superior natural docks for the transportation of bulk raw materials, products, and workers. Most of these areas were rich in natural resources. For example, there were a large number of coal mines in Ruhr, Germany. Starting from coal mining, the industrial chain consisted of coking, electric power, coal chemistry, steel, and other industries emerged continuously and drove the development of machinery manufacturing. The large population working in heavy industries promoted the development of various light industries. At last, a huge industry cluster formed here.

Due to the scientific and technological revolution, or known as the third industrial revolution, and globalization, the modes and drivers of clusters in the late 20th century have shown significant differences from those in the 19th century and have become one of the critical phenomena in the contemporary industrial and economical venue. In the global flow, where production, trade, and investment become increasingly free, clusters have participated in the world economy and demonstrated great vitality as localized economic organizations with specific geographical boundaries. Transportation conditions and communication technology have developed at an unprecedented pace in the past 50 years. Many localized production factors that once restricted the location of production activities in the past lost their inherent nature of monopoly. Liberalization in the international financial market has lowered barriers to capital flows. Standardized production reduces the dependence on workers' special skills. In this context, the production processes are divided into different stages, so enterprises are able to seek different production locations and select between in-house production, outsourcing, and other organizational forms by taking into the different requirements of production factors in each stage and the principle of maximizing the return on investment.

At the same time, national governments, authorities, or industries have been making decisions on the so-called strategic distribution. When participating in the organization and allocation of resources around the world, they have chosen certain regions to agglomerate and seek development, thus forming some new industrial districts or industry clusters. These new industrial districts are different from the traditional industry clusters that have formed naturally, while the new ones are "designed" under certain planning frameworks. These new industry clusters are advantageous with high-level specialization within the industry. In a virtuous circle, the cooperation between specialized enterprises in a cluster and their production efficiency will be improved continuously, then boost the innovation of the whole cluster, and give rise to strong competitive advantages. Nevertheless, it is undeniable that some "man-made" industry clusters have no enough essential conditions to form an operational industrial chain and attract more talented people and resources. They eventually become "empty cities." Ideally, new industrial districts are open rather than closed to the outside world. Based on local historical conditions, the enterprises in an area have gradually enriched original special resources in the area through the operation of local networks and integration of external information. Moreover, the exchange of information and knowledge among enterprises in the area is facilitated by geographical proximity. The innovation culture of the community turns various innovation opportunities into reality, so the area demonstrates extraordinary economic vitality and innovation activities. Supplemented by efficient information dissemination and specialized technology transfer, industry clusters finally take shape and keep growing and expanding. Many traditional industrial cities, such as Milan of Italy, Dortmund in Germany, and Manchester of Britain, have been transformed successfully. On the other hand, Silicon Valley and the Highway 128 region of the United States, the Cambridge Industrial Park of Britain, Bangalore of India, and Antipolis of France tend to plan industry clusters based on historical conditions.

4. Industry Clusters Development Theories

Industry clusters have been economic phenomena in human civilizations since the appearance of production, exchange, distribution, consumption, and other economic behaviors in human history. From the efficiency of centralized cultivation of irrigated agriculture in the lower reaches of the Tigris River and Euphrates River in ancient times to the current traditional industry clusters of the "Third Italy" and the specialized industrial districts in Zhejiang, China, industry clusters have long been beautiful pictures in the history of human civilization (Wang Bufang, 2004). The concepts and connotations of cluster and industry cluster have been constantly studied, developed, and improved by different schools of economics from classical economics to neoclassical economics and newer and further divided academic schools such as new trade economics, new growth economics, and industrial economics.

British economist Alfred Marshall first introduced the issue of "industrial spatial agglomeration" before Michael Porter formally put forth the concept of "industry cluster ."As a typical classical economist, Marshall, in chapters 10 and 11 of *Principles of Economics* published 1890, called large enterprises "internal economies" and concentrated small- and medium-sized enterprises "external economies ."He analyzed and compared the economic efficiency of these two types of economies as to "how far the full economies of the division of labor can be obtained by the concentration of large numbers of small businesses of a similar kind in the same locality; and how far they are attainable only the aggregation of a large part of the business of the country into the hands of a comparatively small number of rich and powerful firms, or as is commonly said, by production on a large scale, or, in other words, how far the economies of production on a large scale must needs be internal, and how far they can be external." Marshall believed that external economies have greater advantages in an environment with continuous advances in knowledge and technology. The cooperation between small- and medium-sized enterprises in an area is flexible and dynamic, so new ideas, information, and technology flow and spread rapidly among enterprises in the area. This helps enterprises in the area realize external economies of scale and then enhance their competitiveness on the basis of mutual trust in the process of division of labor and transactions. This is Marshall's theory on external economies.

After Marshall explained industrial agglomerations from the perspective of economics, German economist Alfred Weber conducted an in-depth study on industrial agglomeration from the perspective of the industrial location theory and put forth the concept of agglomeration economics for the first time (Xu Kangning, 2003). In 1937, Edgar Malone Hoover, an American regional economist, published Location Theory and the Shoe and Leather Industries, in which he put forth the theory of optimal scale of industrial agglomeration. He suggested that any industry has three levels from the perspective of the scale of economy, i.e., (1) economies determined by the scale of each unit (factories, shops, etc.); (2) economies determined by the scale of a single company (i.e., a joint venture); (3) economies determined by the scale of the industry's agglomeration in a certain location. The maximum scale of these economies can be regarded as the optimal scale of units in the location, the optimal scale of the company, and the optimal scale of the agglomeration, respectively. From the 1970s to the 1980s, macroeconomic theories dealt with the changes in the spatial organization of production, and the research on industrial agglomeration mainly focused on flexible "industrial districts" or new "industrial spaces." "Industry clusters have become a frontier topic in research of regional (or national) competitiveness and regional economies" (An Husen and Zhu Yan, 2003). In 1990, Michael Porter put forth the concept of "industry cluster" and the famous "diamond model" from the perspective of national strategy and competitiveness in the book entitled The *Competitive Advantage of* Nations, underlining the important role of industry clusters in the competitiveness of regional and even national industries in the international venue. In 1998, he published another paper entitled " Clusters and the New Economics of Competition," which constructed a complete industry cluster theory from the perspective of the competition theory. He defined an industry cluster as a stable aggregation of small- and medium-sized enterprises and institutions in a specific industry in a certain location with sustainable competitive advantages. As for competitive advantages, industry clusters can improve the productivity of enterprises in the industry clusters, enhance their sustainable innovation ability, reduce their risks in business, and drive their production and development.

Porter's Diamond Model plays an important role in industrial development and research and has become one of the research paradigms applied by follow-up researchers to the research of industries and industry clusters. He took into consideration four attributes of a nation's competitive advantage, i.e., factor conditions, demand conditions, related and supporting industries, and firm strategy, structure, and rivalry. Factor conditions include human resources, natural resources, knowledge resources, capital resources, and infrastructure. Demand conditions mainly refer to the demand in the domestic market. The performance of related and supporting industries examines whether they have international competitiveness in their own industries and the upstream and downstream industries. Porter believed that two-way effects exist between these four attributes, forming a diamond framework (Figure 1-2) (Zeng Guohua and Wu Wenwen, 2019). Government and opportunity are two dynamic factors in addition to the four attributes. Opportunities are uncontrollable, while the influence of government policies is unignorable.

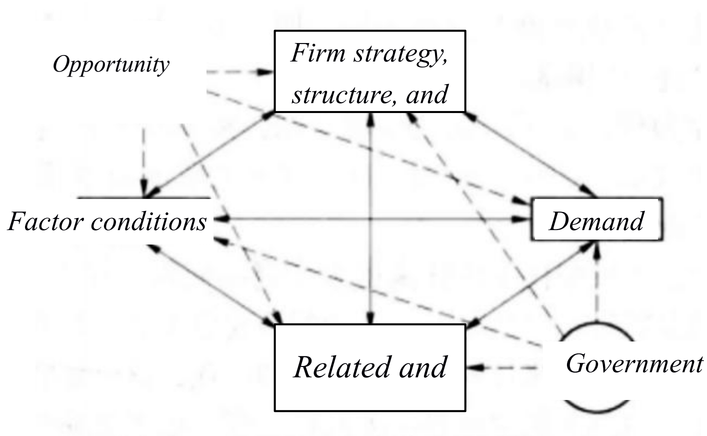

Figure 2 Porter's Diamond Model

Based on Porter's industry cluster theory, academia subsequently applied his model to theoretical analysis and development related to various industries. They also kept putting forth refined and new concepts. For example, the paper "Forms of Regional Development Policy" jointly published by A. Lagendijk and J. Cornford in 2000 distinguished between "cluster" and "clustering." They noted that the latter refers to a process of establishing ties between enterprises and external conditions of clusters. Enterprises gain competitive advantages through the interaction with each other enabled by clustering. Clusters are supported by a stable macroeconomic environment and sound infrastructure, while clustering features low-cost direct intervention through policies and designs and facilitates cluster formation, and drives links between enterprises (Lagendijk and Cornford, 2000).

5. Research on Collaborative Innovation in Industry Clusters

The research on collaborative innovation in industry clusters builds upon the gradual improvement and maturity of innovation-related theories. Scholars have begun to focus on the strategic importance of collaborative innovation in industry clusters, as technological innovation, open innovation, institutional innovation, and other innovation systems have become key sources of sustained competitive advantages for firms, industries, regions, and nations. Scholars have examined the key elements that contribute to collaboration when examining issues of collaborative innovation in industry clusters. In the 1970s, German physicist H. Haken established the synergetics theory of nonequilibrium phase transitions in the book *Introduction to Synergetics*, along with which dissipative structure theory and catastrophe theory constitute the three mainstream schools of system theory research. Synergetics, grounded on the system theory, regards the research subject as a composite system comprised of numerous subsystems, and posits that the disorder within the system originates from the mutual independence of its subsystems. Therefore, the interactions among the subsytems, such as the exchanges and sharing of information and knowledge, can facilitate the formation of an appropriate and orderly operational mechanism for the composite system to transform the disarray within the system, thus leading to the effective qualitative change in the whole system.

In 1998, Michael E. Porter, from an innovative perspective, combined the Diamond Model with the Location Theory to establish a framework of the industry cluster and the new economics of competition, proposing the concept of industry cluster to describe the phenomenon of enterprise clusters in industrialized countries, which is used to summarize the phenomenon of geographically concentrated agglomeration of associated enterprises and related agencies, and further examine the inevitability of the emergence of industry clusters and their contributions to national and regional development and competitive advantage. And the major contributions are reflected in three aspects: first, the complementary advantages and resource sharing due to the interconnections among enterprises within the industry cluster can improve productivity significantly; second, the enterprises within the industry cluster can make faster market response with collaborative operation and knowledge spillover, fostering greater innovation capacity; third, the synergetic growth of enterprise cluster, compared to the solitary development of a single enterprise, has more advantages in terms of resource, information and other aspects, which can achieve the collective progress and development of enterprise cluster to facilitate the industrial growth and enhance the national or regional competitive advantage.

Within the limited geographical scope of cluster, the enterprises are more supposed to seek a collaborative relationship in addition to competition, and it's crucial for enterprises and cluster to pursue innovation and differentiation given the coexistence of competition and collaboration. Therefore, the collaborative innovation by industry cluster has been a key subject of study for both theorists and practitioners.

Zheng Gang et al. (2008) introduced the C3IS collaborative innovation model, which applies the TIM theory to examine the relationships between various key elements such as technology, organization, institution, and market in technological innovation. Liu Guolong (2009) scrutinized the relationships between product innovation, process innovation, and market innovation based on different innovation conditions, suggesting that collaborative innovation has a positive impact on industry development. Bai Junhong et al. (2008) approached the topic from the perspective of innovation activities of enterprises and found the interplay between technology, organization, culture, strategy, and system in the effect of innovation collaboration.

6. Research on Financial Support and Its Efficiency

Scholars hold different understandings of finance from diverse perspectives, leading to the development of a multi-dimensional theoretical system encompassing the theories of fund circulation, financial resources, financial sector, financial instruments, and financial media. According to Levine (2002), financial support factors drive long-term economic growth by enhancing the total factor productivity of the economy rather than just the capital stock. Liu Lichang (2004) conducted an empirical study using 47 listed companies in Shanghai that issued stocks for the first time in 1998. He found that, from the perspectives of scale efficiency and technical efficiency, the equity financing efficiency of Chinese listed companies is relatively low. Liu Fei (2007) measured the relative effectiveness of financial efficiency, financial scale efficiency, and financial input indicators across 30 regions of China with the DEA model, revealing regional variances in financial efficiency. Lin Defa

(2012) evaluated the significance of finance for technological innovation from the perspective of financial functions, concluding that financial support's operational mechanism for promoting technological innovation encompasses four functions: financing, resource allocation, risk management, and project selection of the financial system.

CHAPTER 4

MPACT OF FINANCIAL SUPPORT AND EVALUATION ON COLLABORATIVE INNOVATION IN INDUSTRIAL CLUSTERS

1. Importance of Finance for Collaborative Innovation in Industrial Clusters

On November 20, 2019, the National Development and Reform Commission, Ministry of Finance, People's Bank of China, and other ministries/commissions jointly promulgated the *Opinions on Implementation for Facilitating Deep Integration and Development of Advanced Manufacturing and Modern Service Industries*. The document emphasized the need to increase financial support and enhance the quality and efficiency of financial services in supporting the manufacturing industry's transformation and upgrading. Comprehensive financial support is crucial for the development of industry clusters. First, the modern financial system converts scattered savings into investment capital that supports industrial growth through a range of financial tools. This process solves the insufficient capital at various stages of the industry clustering and improves the efficiency of savings and investment. Second, the process of transforming technological innovation into productivity in industry clusters is inherently uncertain and risky, requiring significant support from both physical and financial capital. An established market mechanism and a complete capital chain are particularly crucial in this process. Third, the market selection and elimination mechanism centered on capital allocation efficiency leads to continuous concentration, exit, transfer, and development of heterogeneous enterprises in emerging industries. This mechanism guides funds to flow toward enterprises with high profitability.

The collaborative innovation system of an industry cluster is a complex network system composed of horizontally and vertically related enterprise clusters, universities, research institutions, and technology centers as the core layer of innovation. Financial institutions, intermediary organizations, governments, and public sectors constitute the service layer of the collaborative innovation system, which has formed in a certain policy environment, social culture, talent market, technology market, and financial market. The innovating entities, service providers, and environmental factors have a significant impact on the process and results of collaborative innovation in industry clusters. The financial elements in the collaborative innovation system in an industry cluster play a crucial role, acting as the "engine" driving collaborative innovation through capital flow, information flow, and material flow. Both the financial endogenous development theory and the financially sustainable development theory support this notion.

The most direct way of financial services supporting collaborative innovation in industry clusters is providing funding support. This is particularly important in China, where many industry clusters start as labor-intensive industries. These clusters rely heavily on labor and production costs, which are essential for their continued growth and for clusters to upgrade and transform into capital-intensive industries. The input of funds can provide a more efficient infrastructure for innovation in industry clusters, boosting production efficiency. It can also attract high-performance human resources and advanced technology, providing an effective guarantee for collaborative innovation in industry clusters.

Industrial clusters form a vital aspect of the regional economy and cannot survive in isolation from the regional environment. The collaborative innovation system of industry clusters is an intricate, open system that consists of the core layer, service layer, and environmental layer. The financial sector provides support for industry clusters influenced by the financial environment and provides intermediary services through financial institutions. In a financial environment, the general credit awareness in the region has an impact on the guarantee system and the proportion of non-performing assets of banks and financial institutions. Moreover, the government's financial support directly affects the attitude of financial institutions toward credit and the financial products offered by financial institutions. As for financial institutions, they serve as a bridge between the finance sector and industry clusters. They are an important component of the service layer of the collaborative innovation system of industry clusters. Different types of financial institutions, including banks, securities companies, and fund management companies, have contributed to the development of the collaborative innovation network of industry clusters.

To obtain the necessary financial investment, industry clusters must have promising development prospects due to the profit-seeking nature of the financial investment. Thus, before accepting technological and market risks, industry clusters or their innovative projects must undergo screening for financial investment. This process not only enhances the elimination mechanism of innovation projects in industry clusters but also effectively optimizes and adjusts the entities and projects in industry clusters.

2. Financial Support System for Collaborative Innovation in Industrial Clusters

By leveraging the complex financial environment and increasingly sophisticated financial rules, the financial support system for collaborative innovation in industry clusters integrates multiple levels of mixed subsystems of macrofinance and microfinance. From the perspective of enterprises, enterprises obtain funds for their economic activities through various channels, including internal funds, government grants, bank loans, and equity financing. From a financial perspective, financial support is comprised of multiple levels, such as service mechanisms, market systems, and operational mechanisms.

Traditional enterprises rely on internal and secured external financing for their funding needs. However, when high-tech industries and collaborative innovation are given national strategic importance, policy finance also supports collaborative innovation in industry clusters. Policy finance, indirect financing through lending from financial institutions, and direct financing from the capital market constitute a comprehensive financial support system for collaborative innovation in industry clusters. Hence, the financial support system for collaborative innovation in industry clusters can be analyzed at the macro and micro levels.

At the macro level, policy finance is the primary form of financial aid that supports collaborative innovation in industry clusters. Typically, policy finance refers to the direct provision of loans or preferential financial policies to achieve specific policy objectives or to offer policy support for certain industries. In China's financial system, policy finance means the exclusive financing conditions offered by the central or local governments to specific enterprises or projects based on the national credit, denoting all the special financial transactions that meet specific policy intentions in the forms of deposits, investments, guarantees, discounts, credit insurance, deposit insurance, and interest subsidies, among others.

Policy finance provides financial support for collaborative innovation in industry clusters through two main channels. The first one involves direct intervention. The government plays a guiding and supportive role in providing credit to specific industrial entities or their business activities by, for example, issuing low-interest or preferential policy loans to high-tech industrial parks through national policy banks. The second involves indirect intervention. The government provides preferential policies for specific industrial entities or their business activities through policy guarantees and fiscal interest discounts to reduce the threshold for them to obtain commercial credit. In the financing of target entities, the government does not directly provide loans to the target entities but plays an indirect supportive role. For example, a local government provides related guarantees for obtaining bank financing for developing high-tech industrial parks or supports the establishment of private financial institutions through preferential subsidy policies.

At the micro level, banks and non-bank financial institutions provide financial services for collaborative innovation in industry clusters. These institutions support industry clusters or their innovation projects by creating specialized loan programs, investing in them through shareholding, participating in venture capital, and other means. The efficiency of micro-level financial support for collaborative innovation in industry clusters refers to the effective outputs and economic performance of collaborative innovation in specific industry clusters to which banks and non-bank financial institutions provide financial services, such as loans, equity holding, and venture capital, to industry clusters and their collaborative innovation projects.

3. Efficiency of Financial Support for Collaborative Innovation in Industrial Clusters

In China's financial support system, deficiencies in the financial infrastructure, scale, and other aspects, as well as the limited financial products, hinder the full potential of collaborative innovation in industry clusters. On the one hand, it is impossible to meet all the financial needs for collaborative innovation in industry clusters due to issues such as the limited availability of financing channels, flawed credit structures, and inadequate alignment between financial products and collaborative innovation projects in industry clusters. On the other hand, given the financial support available, wasting still plague the resource allocation for collaborative innovation in industry clusters, precluding the maximal utilization of financial resources. Thus, scholars worldwide have widely recognized the efficiency of financial support for collaborative innovation in industry clusters as a crucial indicator of the alignment between the models, techniques, and pathways of financial support and the desired financial services.

To realize the objectives of collaborative innovation in industry clusters, innovating entities request financial input of certain quantities and quality in the forms of cash, deposits, loans, gold and silver, foreign currencies, securities, insurance, and trust. From the perspective of the financial utilization rate in the context of the performance of effective collaborative innovation in industry clusters or results of agreed collaborative innovation, this dissertation defines the efficiency of financial support collaborative innovation in industry clusters as the results of effective collaborative innovation in the process of obtaining and allocating these financial inputs. The theories of financial constraints and integration of industry and finance assert that the efficiency of financial support for collaborative innovation in industry clusters can significantly impact both the industry clusters and regional economies at large. First, the efficiency of financial support affects the financing scale of industries in a region; the efficiency of financial support for industry clusters plays a crucial role in determining the effectiveness of financial services as well as the financial aggregating ability; effective innovation in industry clusters can affect the development of finance, the economic development, and the financial sector's ability to attract deposits in the region. Second, the efficiency of financial support plays a significant role in guiding the priorities of regional industries. The pursuit of profitability of the financial sector determines its inclination towards investing in efficient industry clusters or their collaborative innovation projects; therefore, the more efficient the financial support for collaborative innovation in industry clusters, the more noteworthy the results of collaborative innovation; in this case, they get more support from policymakers, financial markets, and financial institutions and serve as priorities of financial support to guide directions of regional industrial development. Third, the efficiency of financial support plays determines the pace and scale of industrial growth; The effectiveness of financial fund raising and distribution in industry clusters directly impacts the results of collaborative innovation as well as the competitiveness and advantages of regional industries. Higher efficiency of financial support can accelerate the development of industry clusters and corresponding regional industries, thereby creating sustained regional competitive advantages and expanding the scale of the regional industries.

4. Financial Support for Development of Lab-Grown Diamond Industry Cluster in Henan

Henan, a province in China, boasts abundant mineral resources and has developed a diamond industry cluster centered around cities like Zhengzhou, Xuchang, Nanyang, and Shangqiu. This cluster integrates research and development, large-scale production, and sales of lab-grown diamond products. Mass production of lab-grown diamond did not start until 2014 though Chinese labs had already produced carat-grade diamond products before that. In 2014, a few enterprises in Zhengzhou, Henan Province took the lead in growing diamonds in the world through technological innovation, product structure adjustments, and expanding industrial chains. Later, other companies, including Zhongnan Diamond and Huanghe Whirlwind, also successfully achieved mass production of lab-grown diamond exceeding three carats per piece. At present, Henan accounts for 80% of China's diamond production with support from a robust public service system consisting of universities and research institutes, such as Zhengzhou University and the Henan University of Technology. From the perspective of the spatial type of labor market, the market of lab-grown diamond has a typical hub and spoke structure, where products or services are sold to a wide range of places surrounding the points of supply.

As for the financial support for collaborative innovation in the Henan lab-grown diamond industry cluster on the macro level, the Henan Provincial Government promulgated the *Plan for Implementing Henan Province's 2022 "Gap-Filling" 982 Project* to support the high-quality development of the manufacturing industry, including six diamond production projects, with a total investment of around RMB 6,920 million. The *Action Plan of Henan Province for Accelerating Advantage Reconstruction and Lane Change in the Material Industry (2022-2025)* prioritizes the development of composite superhard materials, products, and key equipment in various fields, including 5G, chip manufacturing, and oil and gas drilling. Moreover, the plan calls for establishing the world's largest superhard material R&D and production base, with Zhengzhou, Xuchang, Shangqiu, Luohe, Nanyang, and Xinyang as the primary locations. Additionally, Henan Province has the only national superhard material industrial base in China, known as the "National Torch Plan Superhard Material Industrial Base in Henan." In March 2022, the Diamond Material Industry Research Institute was also established in Henan Province. These are examples of the technical support provided by the Henan

Provincial Government to promote the innovation-driven strategy and facilitate the development of the diamond industry in the province.

On the macro level, the financial support for collaborative innovation in industry clusters is mainly provided via financial institutions. The total number of financial institutions, the ratio of banks and non-bank institutions involved, and some other factors affect the financing activities for collaborative innovation in industry clusters. From 2016 to 2022, lab-grown diamond enterprises were inactive in financing activities with infrequent financing transactions in small values. Lab-grown diamond is a competitor of natural diamond. As natural diamond has long been the primary source of the industry, the natural diamond sector has been relatively mature with relatively fixed supply channels, product prices, trading models, etc., leaving limited market space for lab-grown diamond. From the perspective of corporate investment and financing by region, Guangdong, Shanghai, and Henan have been the three provinces/municipalities in China with the highest number of corporate financing events in the diamond industry since 2016. Among them, Shanghai is characterized by the growth of consumer brands and platforms; Henan focuses mainly on lab-grown diamond projects; Guangdong is known for the production and sales of lab-grown diamond and the emergence of new lab-grown diamond brands. The product positioning analyses of enterprises receiving financing between 2016 and 2021 show that lab-grown diamond sales started attracting attention in 2017, and lab-grown diamond production projects received constant financing from 2020 to 2021.

CHAPTER 5

RESEARCH METHODOLOGY

1. DEA Model

The evaluation methods often used by scholars in empirical research on multiple indicators and efficiency issues include regression models and cointegration tests, Cobb Douglas production functions, factor analyses, analytic hierarchy processes, GA-BP models, and data envelopment analyses (DEAs).

The efficiency of financial support for collaborative innovation in industry clusters is evaluated based on the measurement of financial efficiency. Zhang Feng (2010) conducted in-depth research on macro-, meso-, and micro-financial efficiency and established comprehensive evaluation indicators for financial efficiency in China. He conducted a comprehensive evaluation of China's financial efficiency with the cost efficiency of the financial sector as an indicator of micro-financial efficiency, the market allocation coefficient as an indicator of financial market allocation efficiency, and the savings-investment conversion rate as an indicator of macro-financial efficiency. The evaluation made use of the Analytic Hierarchy Process (AHP) and BP neural network. The AHP was used to weigh the financial efficiency indicators, and the BP neural network was then applied to comprehensively evaluate financial efficiency with relevant data from 30 listed banks and securities companies between 2001 and 2008. In the research on the efficiency of financial support for strategic emerging industries, Cheng Gaowei (2013) applied the data envelopment analysis

(DEA) method and an output-oriented BC2 model to analyze the efficiency of financial support for strategic emerging industries in China. His model took the proportion of total outstanding shares in total equity and the asset-liability ratio as input variables, and net return on assets, year-on-year growth rate of total operating revenues, year-on-year growth rate of net profit attributable to shareholders of the parent company, and year-on-year growth rate of basic earnings per share as output indicators. The analysis was done with data from 70 companies listed in the Shanghai and Shenzhen stock markets from 2010 to 2012 for DEA efficiency statistics.

This dissertation defines the efficiency of financial support for collaborative innovation in industry clusters as the effective collaborative innovation results generated by innovation entities of clusters in the process of raising and allocating certain financial inputs to achieve predefined objectives of collaborative innovation. Based on this concept, this dissertation applies the DEA method to the evaluation of the efficiency of financial support for collaborative innovation in industry clusters.

DEA is a method developed by renowned operations researchers A. Charnes (1978), in collaboration with W. W. Cooper and E. Rhodes, for evaluating the relative effectiveness between the same sectors. With different application fields and restrictions, scholars have developed the BC^2 model, FG model, ST model, C^2WH model, and other models based on the initial C^2R model, expanding the practical applications of DEA. The expanding branches of applications have resulted in a more comprehensive range of DEA models. For the research on the efficiency of financial support for collaborative innovation in industry clusters, the C^2R model is used.

DEA is a research method focusing on macroeconomic management, sustainable development, enterprise economy, industrial economy, finance, and other related disciplines and is mainly applied in various fields such as performance, banking efficiency, technological innovation efficiency, and resource allocation. Currently, scholars worldwide use DEA to measure macro financial efficiency, financial market efficiency, and micro banking efficiency with different focuses, resulting in significant theoretical advancements and practical progress.

The C^2R Model, proposed by Charnes, Cooper and Rhodes in 1978, can be used to calculate the effectiveness of resource distribution with constant returns to scale.

In a relative effectiveness assessment of same-type sectors, we assume that there exist n such DMUs (Decision-Making Units). Each DMU accounts for m inputs and p outputs, composing a matrix of both input and output.

element	weight	1	2	···	j	···	n
1	V_1	X_{11}	X_{12}	···	X_{1j}	···	X_{1n}
2	V_2	X_{21}	X_{22}	···	X_{2j}	···	X_{2n}
···	···	···	···		···		···
i	V_i	X_{i1}	X_{i2}	···	X_{ij}	···	X_{in}
···	···	···	···		···		···
m	V_m	X_{m1}	X_{m2}	···	X_{mj}	···	X_{mn}

5.1 Matrix of Input

1	U_1	Y_{11}	Y_{12}	…	Y_{1j}	…	Y_{1n}
2	U_2	Y_{21}	Y_{22}	…	Y_{2j}	…	Y_{2n}
…	…	…	…		…		…
r	U_r	Y_{r1}	Y_{r2}	…	Y_{rj}	…	Y_{rn}
…	…	…	…		…		…
p	U_p	Y_{p1}	Y_{p2}	…	Y_{pj}	…	Y_{pn}

5.2 Matrix of Output

In (5.1), X_{ij} (i=l, 2, ..., m, j=l, 2, ..., n) represents the i-th input of the j-th DMU, V_i represents the metric of the i-th input.

In (5.2), Y_{rj} (r=1,2,...,p, j=l,2,...,n) represents the r-th output of the j-th DMU, U_r represents the metric of the r-th output.

Thus, based on the definition of effectiveness assessment, effectiveness index for the j-th DMU can be represented as:

$$h_j = \frac{\sum_{r=1}^{p} U_r Y_{rj}}{\sum_{i=1}^{m} V_i X_{ij}} \qquad j=1,2,\ldots,n$$

According to C²R Model definition, the j_0 -th DMU delivers relatively optimal effectiveness, and we create the optimized model of relative effectiveness for j_0 :

$$C^2R \begin{cases} max\ h_{j_0} = \frac{\sum_{r=1}^{p} U_r Y_{rj_0}}{\sum_{i=1}^{m} V_i X_{ij_0}} \\ \textbf{s.t.}\ \ \frac{\sum_{r=1}^{p} U_r Y_{rj}}{\sum_{i=1}^{m} V_i X_{ij}} \le 1 \qquad j=1,2,\ldots,n \\ V_i \ge 0,\ i=1,2,\ldots,m \\ U_r \ge 0,\ r=1,2,\ldots,p \end{cases}$$

5.3

In (5.3), $\sum_{r=1}^{p} U_r Y_{rj}$ means total output metric of the j-th DMU, $\sum_{i=1}^{m} V_i X_{ij}$ is total input metric of the j-th DMU. X_{ij} is the i-th input of the j-th DMU, and Y_{rj} is the r-th output of the j-th DMU. We need to find out the right V_i and U_r to make h_{j_0} deliver the max value.

Thus, we do linear programming for the C^2R Model, and define $t = \frac{1}{\sum_{i=1}^{m} V_i X_{ij0}}$, $\mu_r = tU_r, w_i = tV_i$。

Then (5.3) can be transformed as:

$$
C^2R \begin{cases} \max h_{j_0} = \sum_{r=1}^{p} \mu_r Y_{r_{i_0}} \\ \text{s.t. } \sum_{r=1}^{p} \mu_r Y_{rj} - \sum_{i=1}^{m} w_i X_{ij} \le 0 \\ \quad \sum_{i=1}^{m} w_i X_{ij_0} = 1 \\ \quad \mu_r \ge 0, \ r=1,2,\ldots,p \\ \quad w_i \ge 0, \ i=1,2,\ldots,m \end{cases}
$$

5.4

Its dual programming is:

$$
\begin{aligned} & \min \theta \\ & \text{s.t. } \sum_{j=1}^{n} \lambda_j X_{ij} \le \theta X_{i_0}, \ i=1,2,\ldots,m \\ & \quad \sum_{j=1}^{n} \lambda_j Y_{rj} \ge Y_{r_0}, \ r=1,2,\ldots,p \\ & \quad \lambda_j \ge 0 \end{aligned}
$$

Without restriction on θ

5.5

Therefore, C^2R Model can be represented by linear programming problem in (5.5), with empirical meaning: There exists a $\{X_0, Y_0\}$ in all possible production T sets: T={X,Y}, so that when the input is the X_0, any output can't be increased unless decreasing another output element; when the output is the Y_0, any input can't be decreased unless increasing another input element. In the circumstances, we define { X_0 , Y_0 } as effective production combination. This definition is applied to effectiveness determination for DMUs in the DEA model:

$$
\begin{aligned}
& min\theta \\
& \text{s.t. } \sum_{j=1}^{n} \lambda_j X_j + s^- = \theta X_0 \\
& \quad \sum_{j=1}^{n} \lambda_j Y_j - s^+ = Y_0 \\
& \quad \lambda_j \geq 0, \ j=1,2,\ldots,n \\
& \quad s^- \geq 0, \ s^+ \geq 0
\end{aligned}
$$

Without restriction on θ

5.6

In (5.6), {X_0, Y_0} is the production combination of DMU j_0, which means: minimizing θ while keeping production capacity Y_0 unchanged.

The C2R Model can be used to determine whether effective technical efficiency and effective scale efficiency are simultaneously valid: when it meets the condition of θ^*=1 and s^{*+}=0, s^{*-}=0, the DMU is DEA efficient and the economic activity of the DMU is both technically efficient and scale efficient; when it meets the condition of θ^*=1 but at least one input or output greater than 0, the DMU is weakly DEA efficient and the economic activity of the DMU is either technically efficient or scale efficient; when it meets the condition of θ^*<1, the DMU is not DEA efficient and the economic activity of the DMU is neither technically efficient nor scale efficient.

2. Construction of Financial Input Indicator System

The financial services for collaborative innovation in industry clusters constitute a comprehensive financial support system. In selecting the most representative financial put indicators of financial support for collaborative innovation in industry clusters, this dissertation has taken into consideration the five major types of support systems offered of financial support. Based on extensive research into efficiency input indicators made by both domestic and foreign scholars, we have constructed the following financial input indicators: operating costs, government subsidies, and enterprise R&D investment.

The financial supply channels of industrial clusters can be divided into internal supply and external supply from the perspective of the source of funds. Internal supply refers to the way in which enterprises self-satisfy their financial needs by converting retained earnings into investment. External supply is divided into two forms: policy supply and market supply. Market supply includes direct financing and indirect financing, of which direct financing includes securities market supply and venture capital, while indirect financing includes the banking system, trust companies and other channels.

The financial support provided by the government treasury contributes to industrial upgrading and technological innovation. Dietrich (1935) studied the Export Credit Insurance Scheme established in 1919 and considered that the scheme, as a typical policy financial instrument, provided convenient short-term and medium-term loans to exporters, and promoted British trade exports. Fergusson (1948) took the

Industrial Development Bank of Canada, which was founded in 1944 as the research object, and found that the medium-and long-term loans provided by the bank to industrial enterprises promoted the production transformation of small and medium-sized enterprises.

The vast majority of studies point out that firms' innovation performance is positively driven by the intensity of R&D investment, and there exists a strong relationship between firms' R&D investment and finance. Finance helps to solve the financing difficulties of enterprises and increase R&D investment.Kortum and Lemer (2000) studied the role of venture capital in influencing the R&D investment of enterprises, and the results show that compared with ordinary investment, enterprises with more venture capital investment have more R&D output and patents.Rind (2023) et al. found a positive effect of R&D investment on corporate innovation performance after studying the data of 95 listed energy company data from 2010-2018, found that R&D investment has a positive effect on firms' innovation performance.

In macro terms, the financial support provided by government includes both direct interventions and indirect interventions, and indirect interventions include methods such as policy guarantees and fiscal interest subsidies offered by central and local governments. The indicators of macro-level financial support primarily focus on the government's direct intervention strategies, with subsidies provided by government serving as measurement indicators, which can reflect the financial investment provided by government to the projects of collaborative innovation in industry clusters.

In the projects of collaborative innovation in industry clusters, the funds used also include enterprise funds except for the government subsidies. This dissertation refers to such financial investment as enterprise R&D investment. Given the relative short development period of lab-grown diamond industry clusters in China, the financing data of part of the enterprises remain undisclosed. Taking into the accessibility to the data, this dissertation opts to measure financial investment for collaborative innovation financial support efficiency in the industry cluster.

3. Construction of Innovation Output Indicator System

In 1912, the economist Schumpeter first put forward the concept of innovation, and Schumpeter proposed that technological change and the transformation of production mode are decisive to promote the change and reorganization of industrial structure, reallocate and reorganize the internal and external resources of the enterprises, and promote the birth of new enterprises and the demise of the old ones, so as to optimize the market structure and industrial pattern. Innovation in industrial clusters is one of the important factors in enhancing the development capability of clusters and promoting the transformation of cluster enterprises. Innovation performance in a narrow sense refers to the actual innovation output of the cluster, such as the number of new products, relevant patents, and innovative enterprise processes.

In the competitive process in the industry cluster, the innovation entities in the industry cluster, by certain forms of connection among them, engage in behaviors, such as knowledge sharing, information exchange and collaborative innovation, to improve the innovation performance and to obtain sustained competitiveness and competitive advantages. Such entities and their interactions constitute a systematic whole of interdependence and collective development, with a dynamic and stable structure. This innovative system, guided by the policies of government and its departments, centered around technical innovation network, and supported by financial agencies and other intermediary organizations, emerges as a dynamic, open and intricate network system with perfect conditions for drive, support and sustainable development, to commercialize or industrialize innovation process and meeting market demands. The fruits of collaborative innovation are derived from the interactions and collaborations among the entities.

The innovation output indicators chosen in this dissertation are based on the six basic elements specified in the Chinese National Innovation Evaluation Standard System, namely input factors, execution factors, policy environment, infrastructure, output performance, and innovation results. Out of these six elements, output performance and innovation results are the most significant indicators for measuring the innovation output of financial support for collaborative innovation in industry clusters. The innovation results from collaborative innovation in industry clusters are the most direct measure of their innovation capabilities and provide a clear indication of the innovation performance. Generally, the innovation output capability is reelected in new technologies and new economic effects. New technologies are measured by the number of patent applications, while economic effects are measured by operating revenues and net profits.

4. Research Hypothesis

The financing constraints theory asserts that the efficiency of financial support for collaborative innovation in industry clusters can significantly impact both the industry clusters and regional economies at large. First, the efficiency of financial support affects the financing scale of industries in a region; the efficiency of financial support for industry clusters plays a crucial role in determining the effectiveness of financial services as well as the financial aggregating ability; effective innovation in industry clusters can affect the development of finance, the economic development, and the financial sector's ability to attract deposits in the region. Second, the efficiency of financial support plays a significant role in guiding the priorities of regional industries. The pursuit of profitability of the financial sector determines its inclination towards investing in efficient industry clusters or their collaborative innovation projects; therefore, the more efficient the financial support for collaborative innovation in industry clusters, the more noteworthy the results of collaborative innovation; in this case, they get more support from policymakers, financial markets, and financial institutions and serve as priorities of financial support to guide directions of regional industrial development. Third, the efficiency of financial support plays determines the pace and scale of industrial growth; The effectiveness of financial fund raising and distribution in industry clusters directly impacts the results of collaborative innovation as well as the competitiveness and advantages of regional industries. Higher efficiency of financial support can accelerate the development of industry clusters and corresponding regional industries, thereby creating sustained regional competitive advantages and expanding the scale of the regional industries.

Therefore, the dissertation proposes a research hypothesis that cluster enterprises receiving financial support manifest characteristics of common growth and development and drive the development of other enterprises on the entire industrial chain and within the cluster.

5. Sample Selection

For the authenticity of indicator data, this dissertation chooses Henan Province, a region with significant cluster characteristics, as the area for sample selection and chooses representative listed companies as similar DMUs to collect input-output data. This study selects seven cluster representative listed companies, namely North Industries Red Arrow, SINOMACH Precision Industry, CHJ Jewellery, SF Diamond, Jingsheng Mechanical & Electrical (JSG), Yuyuan and Huifeng Diamond, as the research samples, and collects their R&D investment amount and special government subsidies from 2017 to 2021 as the input indicators, and collects their operating income, net profit and number of patent applications data as the output indicators.

In terms of sample company selection, this study chooses listed companies that cultivate the diamond industry cluster for two reasons. First, China's cultivated diamond industry started late, and the cultivated diamond industry is mainly concentrated in the Henan region, while the number of companies in other regions is very small, with small scale and low capacity. Second, small enterprises that are not listed companies have a short development time and do not disclose relevant information, so it is difficult to collect data over a long period of time.

CHAPTER 6

EVALUATION OF EFFICIENCY OF FINANCIAL SUPPORT FOR COLLABORATIVE INNOVATION IN INDUSTRY CLUSTERS BASED ON THE DEA MODEL

1. Correlation Analysis of Input-Output Data

In this study, the input indicators are operating costs, enterprise R&D investment, and government subsidies of enterprises in the process of collaborative innovation in clusters, while the output indicators are operating revenues, net profit, and patent applications. The basic data about various indicators of the 7 sample companies from 2017 to 2021 mainly come from the National Innovation Fund's website, innovation project reports, and real-time stock market information on eastmoney.com.

Table 1 Sample Company Information

Sample No.	Name	Stock code
1	North Industries Red Arrow	000519
2	SINOMACH Precision Industry	002046
3	CHJ Jewellery	002345
4	SF Diamond	300179
5	Jingsheng Mechanical & Electrical (JSG)	300316
6	Yuyuan	600655
7	Huifeng Diamond	839725

Before incorporating data into the DEA model, conducting correlation analysis on input-output indicator data is a prerequisite for evaluating the efficiency of financial support to establish a positive correlation between financial inputs and innovation outputs. In this dissertation, the sample data span from 2017 to 2021. The correlation analysis between the input-output indicator data of sample companies over the five years is shown in Tables 1-2 through 1-6.

Table 2 Correlation Analysis of Input-Output Data of Sample Companies in 2017

Correlation coefficient	Net profit	Operating revenues	Patent applications	Operating costs	R&D investment	Special government subsidies
Net profit	1	0.84	0.81	0.07	0.28	0.18
Operating revenues	0.84	1	0.92	0.04	0.22	0.11
Patent applications	0.81	0.92	1	0.05	0.21	0.13
Operating costs	0.07	0.04	0.05	1	0.29	0.62
R&D investment	0.28	0.22	0.21	0.29	1	0.49
Special government subsidies	0.18	0.11	0.13	0.62	0.49	1

Table 3 Correlation Analysis of Input-Output Data of Sample Companies in 2018

	Net profit	Operating revenues	Patent applications	Operating costs	R&D investment	Special government subsidies
Net profit	1	0.97	0.96	0.05	0.17	0.37
Operating revenues	0.97	1	0.99	0.05	0.21	0.28
Patent applications	0.96	0.99	1	0.06	0.21	0.28
Operating costs	0.05	0.05	0.06	1	0.29	0.64
R&D investment	0.17	0.21	0.21	0.29	1	0.51
Special government subsidies	0.37	0.28	0.28	0.64	0.51	1

Table 4 Correlation Analysis of Input-Output Data of Sample Companies in 2019

Correlation coefficient	Net profit	Operating revenues	Patent applications	Operating costs	R&D investment	Special government subsidies
Net profit	1	0.99	0.98	0.17	0.02	0.09
Operating revenues	0.99	1	0.99	0.15	0.05	0.08

Table 4Correlation Analysis of Input-Output Data of Sample Companies in 2019(continue)

Correlation coefficient	Net profit	Operating revenues	Patent applications	Operating costs	R&D investment	Special government subsidies
Patent applications	0.98	0.99	1	0.16	0.04	0.05
Operating costs	0.17	0.15	0.16	1	0.38	0.39
R&D investment	0.02	0.05	0.04	0.38	1	0.34
Special government subsidies	0.09	0.08	0.05	0.39	0.34	1

Table 5 Correlation Analysis of Input-Output Data of Sample Companies in 2020

Correlation coefficient	Net profit	Operating revenues	Patent applications	Operating costs	R&D investment	Special government subsidies
Net profit	1	0.94	0.94	0.07	0.06	0.53
Operating revenues	0.94	1	0.99	0.09	0.24	0.45
Patent applications	0.94	0.99	1	0.06	0.21	0.28

Table 5 Correlation Analysis of Input-Output Data of Sample Companies in 2020 (continue)

Correlation coefficient	Net profit	Operating revenues	Patent applications	Operating costs	R&D investment	Special government subsidies
Operating costs	0.07	0.09	0.06	1	0.09	0.67
R&D investment	0.06	0.24	0.21	0.09	1	0.33
Special government subsidies	0.53	0.45	0.28	0.67	0.33	1

Table 6 Correlation Analysis of Input-Output Data of Sample Companies in 2021

Correlation coefficient	Net profit	Operating revenues	Patent applications	Operating costs	R&D investment	Special government subsidies
Net profit	1	0.94	0.93	0.04	0.53	0.46
Operating revenues	0.94	1	0.99	0.08	0.07	0.15
Patent applications	0.93	0.99	1	0.08	0.18	0.13
Operating costs	0.04	0.08	0.08	1	0.02	0.56

Table 6 Correlation Analysis of Input-Output Data of Sample Companies in 2021.

(continue)

Correlation coefficient	Net profit	Operating revenues	Patent applications	Operating costs	R&D investment	Special government subsidies
R&D investment	0.53	0.07	0.18	0.02	1	0.61
Special government subsidies	0.46	0.15	0.13	0.56	0.61	1

The correlation coefficient measures the closeness between variables, represented by r, with $-1 \leq r \leq 1$. When r>0, the two variables are positively correlated; when r<0, the two variables are negatively correlated; when r=0, there is no correlation between the two variables. From Tables 1-1 through 1-5, it can be seen that the correlation coefficients between input indicators and output indicators are all greater than 0. That is, when an input indicator increases, the output indicator's value will also increase accordingly, which meets the research requirements.

2. Empirical Results and Analysis

This dissertation studies the efficiency of financial support for collaborative innovation in industry clusters with a DEA model. Matlab's specialized mathematical software is used to calculate the comprehensive efficiency, pure technical efficiency, and scale efficiency of sample cluster companies from 2017 to 2021. The empirical results are shown in Tables 1-7.

Table 7 Empirical Results of Comprehensive Efficiency, Pure Technical Efficiency, and Scale Efficiency of Sample Cluster Companies

Sample	Efficiency in 2017			Efficiency in 2018			Efficiency in 2019			Efficiency in 2020			Efficiency in 2021		
	Crste	**Scale**	**Vrste**	**Crste**	**Scale**	**Vrste**	**Crste**	**Scale**	**Vrste**	**Crste**	**Scale**	**Vrste**	**Crste**	**Scale**	**Vrste**
1	0.58	0.58	1	0.75	1	0.75	0.41	0.97	0.42	0.58	0.95	0.61	0.78	0.96	0.81
2	0.92	0.92	1	0.78	1	0.78	0.70	0.93	0.76	1	1	1	1	1	1
3	0.54	0.97	0.56	1	1	1	0.25	1	0.25	0.64	0.96	0.67	1	1	1
4	0.51	1	0.51	0.58	1	0.58	0.44	1	0.44	1	1	1	0.8	0.89	0.9
5	0.98	0.98	1	1	1	1	1	1	1	0.92	0.99	0.93	0.81	1	0.81
6	1	1	1	0.92	0.96	0.96	1	1	1	1	1	1	1	1	1
7	0.28	1	0.28	0.61	0.86	0.72	0.87	0.87	0.79	0.95	0.95	1	0.98	1	0.98
Mean	0.70	0.92	0.76	0.81	0.97	0.82	0.64	0.97	0.67	0.87	0.94	0.74	0.91	0.97	0.70

As shown in Tables 1-8, crste represents comprehensive efficiency; vrste represents pure technical efficiency; scale represents scale efficiency. The relationship between the three is: crste=vrste × scale. In economic terms, the pure technical efficiency accounts for the production efficiency under the impact of management, technical and other factors without considering the scale efficiency. Effective points of pure technical efficiency lie in the production function. The scale efficiency is the production efficiency affected by the size of the enterprise. By analyzing the scale efficiency curve, there is a point of optimal economic benefits for the enterprise at a certain scale, which is referred to as the effective scale. The comprehensive efficiency is an all-encompassing measure that takes into account scale benefits, making it a key indicator for evaluating the resource allocation ability, utilization of production factors, and other strengths of DMUs being evaluated. It is the product of the scale efficiency multiplied by the pure technical efficiency. Time is a factor in this dissertation for analyzing the data of relative efficiency results.

From the perspective of the number of effective DMUs, there were three effective decision-making units in 2021, accounting for 42.85% of the sample companies. These companies were effective in terms of comprehensive efficiency, pure technical efficiency, and scale efficiency, relatively outperforming other years. The number of effective DMUs from 2017 to 2021 shows an increasing trend year by year, and the specific numbers and annual proportions are shown in Table 1-8.

Table 8 Changes in Number of Effective DMUs

Effective DMUs/year	2017	2018	2019	2020	2021
Nos	1	2	2	3	3
Proportion	14.28%	28.57%	28.57%	42.85%	42.85%

From the perspective of time, if the efficiency values are observed by periods, three companies had a comprehensive efficiency of 1 in 2021, which means that three out of the seven sample companies were able to effectively control inputs to fulfill the predefined innovation performance objectives while achieving the pure technical efficiency and scale efficiency. Three enterprises had comprehensive efficiency values between 0.8 and 1, which means that the remaining enterprises were able to achieve satisfactory production efficiency. With slight improvements, they should have been able to achieve the optimal input-output value and enterprise scale. These data indicate that such enterprises were able to achieve an effective scale efficiency and find their effective production scale in 2021.

Pure technical efficiency analysis is to analyze the innovation efficiency of industrial cluster enterprises, reflecting the enterprises' ability of capital investment and management, resource allocation, technology introduction and innovation, capital flow and follow-up supervision. The reason why the comprehensive efficiency fails to be effective is the lower pure technical efficiency. As can be seen from Tables 1-9, the pure technical efficiency of cluster enterprises is not stable, with four enterprises with effective pure technical efficiency in 2017 and only two enterprises with effective pure technical efficiency in 2018 and 2019, and their values fall in 2021 after rebounding in 2020. Meanwhile, from 2017 to 2019, about half of the enterprises have a pure technical efficiency value lower than 0.8.This reflects that half of the enterprises have relatively irrational capital allocation and their technological innovation capacity needs to be further strengthened.

Scale efficiency is the production efficiency affected by the scale factor, reflecting the gap between the actual scale and the optimal production scale. In terms of scale efficiency, five enterprises had effective scale values in 2021, accounting for 5/7. Two enterprises with scale efficiency values between 0.8 and 1, accounting for 2/7 of the entire sample. These data indicate that over 80% of enterprises were able to achieve an effective scale efficiency and find their effective production scale in 2021. Similarly, the number of enterprises with efficiency values in other years can be calculated based on the efficiency values. The specific years and efficiency values are shown in Tables 1-9.

Table 9 The Specific Years and Efficiency Values

Year	Efficiency value	Equal to 1	[0.8,1)	[0.6,0.8)	[0.4,0.6)	[0,0.4)	Total
2017	Crste	1	2	1	2	1	7
	Scale	3	3	-	1	-	7
	Vrste	4	-	2	-	1	7
2018	Crste	2	1	3	1	-	7
	Scale	5	2	-	-	-	7
	Vrste	2	1	3	1	-	7
2019	Crste	2	-	2	2	1	7
	Scale	4	3	-	-	-	7
	Vrste	2	-	2	2	1	7
2020	Crste	3	2	1	1	-	7
	Scale	3	4	-	-	-	7
	Vrste	4	1	2	-	-	7
2021	Crste	3	3	1	-	-	7
	Scale	5	2	-	-	-	7
	Vrste	3	4	-	-	-	7

From the perspectives of comprehensive efficiency, pure technical efficiency, and scale efficiency, the efficiency of financial support for the cluster enterprises kept improving. From the perspective of the average efficiency value, the average comprehensive efficiency of the sample companies from 2017 to 2021 was 0.7, 0.81, 0.64, 0.87, and 0.91, respectively, showing a satisfactorily stable growth trend except for a decline in 2019.

Second, from the perspective of the proportion of efficiency values by segment, the degree of collaborative innovation in the cluster gradually increased over the five years, and the collaborative innovation network has gradually matured. From Table 5-8, the proportion of DMUs with a comprehensive efficiency value of 1 from 2017 to 2021 was 14.28%, 28.57%, 28.57%, 42.85%, and 42.85%, respectively. The proportion of DMUs with a value above 0.8 was 28.57%, 14.28%, 0%, 28.57%, and 42.85%, respectively. The proportion of DMUs with a value above 0.6 was 14.28%, 42.85%, 28.57%, 14.28%, and 14.28%, respectively. It can be observed that the proportion of DMUs with high efficiency values is increasing. On the one hand, the cluster enterprises manifest a cluster characteristic of growing and developing together. On the other hand, this also suggests that cluster enterprises have stronger collaboration awareness and accelerate knowledge sharing during their development. The key enterprises' growth in the cluster drives the progress of the entire industrial chain and other enterprises, ultimately enhancing the overall efficiency of financial support for collaborative innovation in the cluster.

Third, from the perspective of the proportion of effective DMUs, there is still a large room for improvement in the efficiency of financial support for collaborative innovation in the cluster. Though the efficiency of the sample cluster companies kept improving in the past five years and manifested characteristics of the cluster, there is still a large room for improvement. In 2017, there was one effective DMU, and only one cluster enterprise was able to achieve effective financing and production. Only two DMUs had a comprehensive efficiency higher than 0.8. Based on the growth trend of the past five years, only half of the DMUs ratio will be effective in the next three years.

CHAPTER 7

STRATEGIES FOR IMPROVING EFFICIENCY OF FINANCIAL SUPPORT FOR COLLABORATIVE INNOVATION IN LAB-GROWN DIAMOND INDUSTRIAL CLUSTER

Henan boasts of a strong industrial foundation and abundant innovation resources, has clear positioning of industry clusters and collaborative innovation, and provides favorable macroeconomic policies. Local large-scale lab-grown diamond enterprises have a relatively strong foundation. After preliminary R&D and technological accumulation, they gradually integrate the upstream and downstream processes of the industrial chain and leverage the advantages of the industry cluster while consumption in the lab-grown diamond market has grown fast in recent years; Based on an analysis of results over time, it can be concluded that the efficiency of the sample companies in the cluster has improved continuously and the level of collaborative innovation in the cluster keeps growing, and the collaborative innovation network has taken shape.

First, improve the management efficiency and make the best of financial resources.

Adequate financial inputs serve as a foundation of collaborative innovation in industry clusters but are not the only safeguard for obtaining excellent innovation results. From the test data of the financial support efficiency of sample companies, it can be seen that in 2021, there were only three companies with pure technical efficiency equal to 1, while there were five companies with scale efficiency equal to

1. This indicates that most companies were able to achieve scale efficiency and find an effective production scale for the enterprise. However, their production efficiency was low due to poor management and other reasons, so their pure technical efficiency values were low compared to the scale efficiency values, resulting in low comprehensive efficiency.

It is crucial to enhance the management efficiency to maximize innovation outputs while the financial inputs are limited. The efficiency of financial support for collaborative innovation in industry clusters is affected by the input redundancy. To improve the management efficiency and use available funds effectively, it is essential to adopt a market-oriented, efficiency-oriented, and quality-oriented approach to management. Industrialization and commercialization should be sought for innovation results to generate economic value. It is advisable to introduce the world's state-of-the-art equipment and management methods and focus on the long-term benefits and efficiency of the cluster enterprises.

Second, it is imperative to establish a complete collaborative innovation system for the lab-grown diamond industry cluster.

As the analysis of results over time shows, DMUs with higher comprehensive efficiency values kept improving partially due to the increasingly improved innovation entities in the industry cluster. In the network of entities as part of the collaborative innovation system of an industry cluster, the enterprise cluster is the ultimate executor of collaborative innovation in the cluster and the main component of the cluster. They play a vital role in identifying market trends, leveraging policies, technology, and economic conditions, addressing socio-cultural factors, and connecting with other organizations in the cluster. They are important nodes in the collaborative innovation network system of the industry cluster. Universities, research institutions, and enterprise clusters are the main entities of technological innovation in the industry cluster and carry out innovative activities such as production technology improvement and service model updating through market and technological information communication, experience exchanging, knowledge sharing, and infrastructure sharing among them. Financial institutions serve the technological innovation network by facilitating the flow of capital, information, and materials and providing financial support for all activities in the collaborative innovation system of the cluster.

In collaborative innovation in industry clusters, enterprise clusters, universities, research institutions, financial institutions, intermediary organizations, governments, the public sector, and other innovation entities form bonds, whether weak or strong, through both formal and informal collaboration. Together, they create a collaborative innovation network system of the industry clusters. Each part of the system structure plays a distinct role. For example, the collaborative innovation between enterprises, universities, and research institutions constitutes the mechanism for technological innovation entities in the cluster. The evaluation indicators of innovation performance mainly reflect the technological innovation capability of the cluster. A comprehensive and efficient collaborative innovation system of an industry cluster can be formed by linking various structures made up of diverse and the bonds between them and integrating the functions of each component.

CHAPTER 8

SUMMARY AND PROSPECT

This dissertation expounds on the evaluation of methodology and efficiency of financial support for collaborative innovation in industry clusters, and presents an empirical study of the efficiency of financial support for collaborative innovation in industry clusters with the data envelopment analysis (DEA) method and a sample consisting of companies from the lab-grown diamond industry cluster in Henan.

The analysis of results over time shows that the efficiency of the sample companies in the cluster kept improving in general from 2017 to 2021, and the level of collaborative innovation in the cluster was also increasing. However, there is still a large room for improvement in terms of the absolute value of efficiency. A typical example is their pure technical efficiency fell behind the improvement in the scale efficiency. Based on the theoretical analysis and empirical findings, this dissertation gives proposed strategies for improving the efficiency of financial support for collaborative innovation in industry clusters, including enhancing the management efficiency and establishing a collaborative innovation system that is built upon a certain scale of financial inputs.

The efficient development of collaborative innovation in industry clusters requires a positive interaction between finance and the industrial economy, as financial support serves as a booster for collaborative innovation in industry clusters. Moreover, the unique industrial environment and symbiotic mechanism in industry clusters could enhance the effect of financing. The development of the lab-grown diamond industry cluster in Henan testifies to the mechanism of financial support for collaborative innovation in industry clusters, particularly for emerging industries. For enterprises in emerging industries to achieve effective innovation objectives, a key pathway is to raise funds as a cluster, allocate financial resources for specialization and collaboration, and leverage the advantages of innovation entities in the industry cluster. Appropriate use of financial resources helps clusters boost their innovation capability, achieve higher economic performance, and open up new opportunities for growth for innovative enterprises.

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