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Elucidating the industrial cluster effect from a system dynamics perspective

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This study applies the system dynamics (SD) methodology to explore factors affecting the industrial cluster effect, which is crucial in determining national and industrial competitive advantage. A literature review finds few studies that utilize SD to investigate factors affecting the industrial cluster effect. In a global business environment, competition is not just between individual companies and supply chains, but also among companies in regional clusters. The concept of SD, devised by Jay W. Forrester et al, helps mankind realize the variation of a complicated system, and perceive how an internal feedback loop within a system impacts whole system's behavior. This study establishes a dynamic model of various factors of industrial cluster effect through the causal loop diagram also known as the cause-and-effect chain. This study considers four important interactive dimensions of industrial competitiveness: manpower, technology, money, and market flows. This study also constructs a comprehensive causal loop diagram of the industrial cluster effect. All factors in the cause-and-effect chains influence positively the industrial cluster effect. The SD approach is adopted to analyze the complicated relationship of factors affecting industrial cluster effect. The SD approach is more effective than other methodologies.

Keywords: System dynamics; Industrial cluster effect; Competitive advantage

1. Introduction

The competitive environments in industry have recently begun to change, with the changes being especially dramatic in the manufacturing industry. Prior the late 1970s, semiconductor and electronics firms used technology to open up new markets. Semiconductor technology was new and developing rapidly, and was too complex and too important to be developed and commercialized adequately within a single organization. Multiple sources of innovation thus were beneficial (Grindley and Teece, 1997). Firms relied primarily on time-to-market advantages to maintain competitive advantage; new application trends shortened product life cycles. Moreover, the technology's complexity and R&D scale of investment were increasing, thus promote firms' business risks.

In a global market, industries can spread operations through the world. Carrie (2000) notes the emergence of a new form of competition, namely, competition between regional clusters, which could contribute to multinationals' global activities. Furthermore, a consensus reached at the international working conference on Strategic Management of the Manufacturing Value Chain identified the implications of the changing basis of competition. In the new millennium, competition will be between clusters of companies, customers, suppliers, and other private and public stakeholders (including governments, academic institutions, research establishments, financial institutions, etc.) rather than between individual companies (Bititci and Carrie, 1998).

Technological innovation is essential to competitive advantage, and it is increasingly recognized that the dynamism of a competitive private enterprise system flows from the development and application of new technology and adoption of new organizational forms. Many economists acknowledge that technological innovation and progress result from numerous interactions between industries and technologies (Schumpeter, 1935; Rosenberg, 1982; Callon, 1992). Geographical concentration of an industry can boost

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technological interaction among firms. Swann and Prevezer (1996) defined clusters as groups of firms within a given industry in a single geographical area.

Since Porter's development of the concept of 'industrial clusters' in the 1980s, it has come to be considered an important factor in innovation, entrepreneurship and technology industries (e.g. Gover, 1993; Swann and Prevezer, 1996; Bergeron et al., 1998; Po-Hsuan Hsu et al., 2003). Most governments have made clusters central to their economic development strategies; however, many factors influence the industrial cluster effect, interactions among factors exist, making it worthwhile to explore the dynamic and complex system of industry clusters. A literature review finds few studies that utilize SD to investigate factors affecting the industrial cluster effect. This study utilized the SD method to examine the factors affecting industrial clusters and feedback effects.

Recent industrial environments have particularly involved specialized division of labor, and the best way for enterprises to continuously create competitive ability is to draw support from supply chain partnerships, and industrial clusters aspect is just for describing the relation of the supply chain. Governments can forecast the industrial development through SD, and can step in as appropriate to assist industry towards beneficial development. The primary contributions of this research are apply the system dynamics (SD) approach to explore the factors that impact the industrial cluster effect, and to establish the dynamic model of various factors of industrial cluster effect through the causal loop diagram (or cause-and-effect chain).

The rest of this paper is organized as follows. Section 1 describes the basic concepts of competitive advantage, industrial clusters and system dynamics. Section 2 presents the conceptual framework used in this study. Section 3 illustrates the competitive advantage gained through establishing industrial clusters. Section 4 defines the models used in this research, including manpower, technology, money and market flows. Section 5 establishes both individual and comprehensive causal loop diagrams. Finally, Section 6 presents the conclusions.

2. Literature review

The following reviews the literature on competitive advantage, concept of industrial clusters and system dynamics.

2.1. Competitive advantage

Competitive advantage is a commonly used phrase. As Porter mentions in *The Competitive Advantage of Nations* (1990), competitive advantage lies at the heart of firm performance in competitive markets. However, several decades of vigorous expansion and prosperity have caused many firms to lose sight of competitive advantage in their scramble for growth and pursuit of diversification. Today competitive advantage is crucially important to a firm. A firm's competitive advantage can derive from numerous sources, like lower cost, superior services or products. Achieving competitiveness requires companies to perform discrete activities such as processing orders, calling on customers, assembling products and training employees, thus creating a sustained competitive advantage.

To most manufacturers, technology is an integral part of their organizational knowledge, and provides distinct capabilities and competitive advantage (Kogut and Zander, 1993). To best make use of this resource, companies are extending the application of their knowledge through technology transfer (Bruun and Bennett, 2002) and Lin B-W (2003) also pointed out that firms in developing countries with limited R&D resources achieve sustainable competitive advantage through technology transfer.

Technology transfer and building strong relationships between complementary organizations facilitates the formation of industrial clusters and improves competitiveness. Dayasindhu (2002) describes the real purpose of industrial clusters as being to achieve global leadership vis-à-vis competitors, and make their constituent organizations globally competitive. Porter (1998) points out that competitiveness is achieved in three ways: increasing organization productivity; driving the direction and pace of innovation; and, stimulating new organizational institutional growth.

2.2. Concept of industrial clusters

Ever since Stanford University in California became the foundation for Silicon Valley, many researchers have studied the economics of industrial location and, in particular, the issue of industrial clusters. This field has been researched by economic geographers and through detailed case studies, examples include Dorfman (1988); Hall and Markusen (1985); Saxenian (1994). Research, technology and science parks have been established close to universities in various US cities, as well as in other industrialized nations (Clark, 2003).

The theoretical basis of the cluster concept as a factor in competitive advantage, was proposed by Porter (1990). According to Porter (1990, 1998, 2000), an industrial cluster is a geographic cooperative group that includes suppliers, consumers, peripheral industries, governments, and supporting institutions such as universities. Porter argued that cluster strength is based on several interacting factors, that are grouped into four headings, and arranged in a four-dimensional diamond metaphor: firm strategy, structure and rivalry; demand conditions; related and supporting industries; and factor conditions (Porter, 1990, 1998, 2000). However, Hill and Brennan (2000) define an industrial cluster as a system that causes component firms and institutes to generate higher unit earnings and more efficient operations owing to innovations stimulated by intense

competition and cooperation within clusters. Hill and Brennan propose another structure for an industrial cluster grounded in five elements: driver industries, technology, labor, consumer industries and, supplier industries. (Hill and Brennan, 2000; Po-Hsuan Hsu et al., 2003)

The economy today is increasingly considered knowledge-based; a knowledge-based economy is one in which knowledge is the most important resource and learning is the most important process (Bergeron et al., 1998). Baptista and Swann (1998) also emphasize that firms in strong industrial clusters or regions are more likely to innovate than other firms, one of the main reasons is the spillover of technological knowledge. Additionally, Porter (1998) points out that understanding industrial clusters facilitates organizations in making more informed decisions about location selection, fostering productive social relation ships in those locations, and working with other constituents to nurture the cluster.

Although the term 'clusters' has only recently become commonplace, some of clusters have long been extremely well known, including the electronics industry in California, timber products in Sweden, or clothing and fashion in Northern Italy. Carrie (2000) defines clusters as networks of companies, their customers and suppliers of all the relevant factors, including materials and components, equipment, training, finance, etc. Gary (1994) notes the following species of industrial clusters: relations between buyer and supplier, competitor and cooperator, sharing resources jointly. Carrie (2000) mentioned that clusters are a form of virtual enterprise, and, furthermore, some components of clusters can serve several industries and be members of several clusters; therefore, the field of industrial clusters is generally larger than that of industry, and it can seize the connect point among factories and industries, complement, spillover effect of technology, technological competence, information, marketing and demands of customer. The conditions of industrial cluster formation include human resource quality, technological knowledge, capital, faultless infrastructure and foundation of technique (Porter, 1998), university and R&D center (Olson, 1998) and entrepreneurial spirit (Bahrmi et al., 1995). Fig. 1 maps the conditions of industrial clusters.

2.3. System dynamics methodology

System dynamics (SD) is a methodology, a tool and a concept. SD: was developed by Professor Jay W. Forrester et al. at the Sloan School of Industrial Management of the Massachusetts Institute of Technology. Professor Jay W. Forrester pioneered important ways in each of engineering-related progress areas. Forrester's move in 1956 from head of the Computer Division at the M.I.T. Lincoln Laboratory (under which the SAGE system was developed) to a professorship in the M.I.T. School of Industrial Management, now called the M.I.T. Alfred P. Sloan School of Management, signaled the beginning of the industrial dynamics program, which has now broadened into SD. System dynamics is also referred to as industrial dynamics and is increasingly applied widely in the social sciences.

Roberts (1978) defines SD as the application of feedback control systems, principles and techniques to managerial, organizational, and socioeconomic problems; for managerial use, SD approach advocates seek to integrate the several functional areas of an organization into a conceptual and meaningful whole, and provides an organized and quantitative basis for designing more effective organization policy. Forrester (1961) mentioned that the SD approach was made feasible by advances in information feedback control systems design and analysis, modeling of decision-making processes, simulation techniques and techniques for electronic data processing (largely a result of military research and development).

Additionally, Roberts (1978) provided two aspects of SD philosophies: that the behavior (or time history) of an organization results principally from its organization structure; and, organization structure includes physical

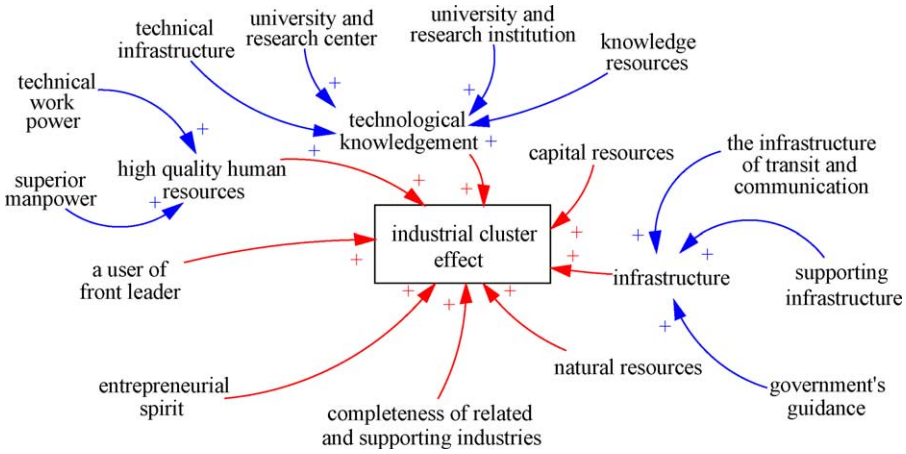

Fig. 1. Conditions of forming industrial cluster effect.

aspects of plant and production processes, and more importantly, the policies and traditions, both tangible and intangible, that dominate organizational decision-making. This structural framework contains sources of amplification, time lags, and information feedback, similar to complex engineering systems. Engineering and management systems that embody these characteristics display complicated response patterns to relatively simple system or input changes. The analysis of large nonlinear systems of this sort is a major challenge to even the most experienced control systems engineer. Effective and reliable redesign of such a system is challenging. The subtleties and complexities in the management area make these problems even more severe. In this study the structural orientation of system dynamics provides a beginning for replacing confusion with order.

The second useful characteristic of system dynamics philosophy is that it considers organizations in terms of their common underlying flows instead of in terms of separate functions. Flows of people, money, materials, orders, and capital equipment, and information flows, can be identified in all organizations. The flow structure orientation causes the viewer (manager or analyst) to cross suborganization boundaries naturally. This orientation dispels the component approach to organizations, which promotes inter-organizational conflict and unrecognized sub-optimization. A meaningful systems framework is a result of tracing cause-and-effect chains through relevant flow paths.

The SD approach (Roberts, 1978) begins with understanding the system of forces that created and continues to sustain a problem. A formal model is then developed as soon as relevant data are gathered from a variety of sources and a rudimentary measure of understanding is achieved. This model initially uses in the format of a set of logical diagrams showing cause-and-effect relationships. The visual model is then translated into a mathematical model. This model is criticized, revised, criticized again, in an iterative process that continues as long as it is useful. Just as the model is improved from successive exposure to critics, a successively better understanding of the problem is achieved by process participate.

The SD method is often used to solve managerial problems. Managerial systems contain numerous variables that are known to be relevant and believe to be related to one another in nonlinear fashions. The behavior of such systems is complex far beyond the capacity of intuition. Thus, computer simulation thus is one of the most effective methods available to supplement and correct human intuition.

The real world involves numerous complex social, economic and organizational feedback systems. Notably, four hierarchically different levels of feedback system structure exist (Roberts, 1978): variable, linkage (or link), feedback loop, and feedback system. A variable is a quantity that changes over time. When a variable is not affected by other variables inside the system being analyzed, it is termed ‘exogenous,’ or outside of the system, otherwise termed ‘ endogenous’. A feedback loop consists of two or more linkages connected such that, beginning with any variable, the arrows can be followed until they return to the starting variable. Roberts defines a feedback system as two or more connected feedback loops. Besides, SD employs a causal loop diagram to analyze a complex managerial problem.

In developing a causal loop diagram each link is given a + or − directional sign, generally shown near the arrow head and is referred to as a plus (or positive) or a minus (negative) linkage. Just as linkages have two possible directions, feedback loops have two possible polarities, positive (+) or negative (−). The positive symbol, found in the middle of a closed feedback loop, tells the loop acts to reinforce variable changes in the same direction as the change, and the loop is called a positive feedback loop. Otherwise, the negative symbol, found in the middle of a closed feedback loop, tells the loop to acts opposite to a change, and is called a negative feedback loop.

3. Conceptual framework

This study adopted a qualitative method since this approach is best suited to understanding complex socio-economic phenomena. This study follows an interpretive approach and adopts an SD perspective to demonstrate the influential factors of industry clustering. Related literature was reviewed and a conceptual framework was developed (see Fig. 2). Besides, the construct conditions of

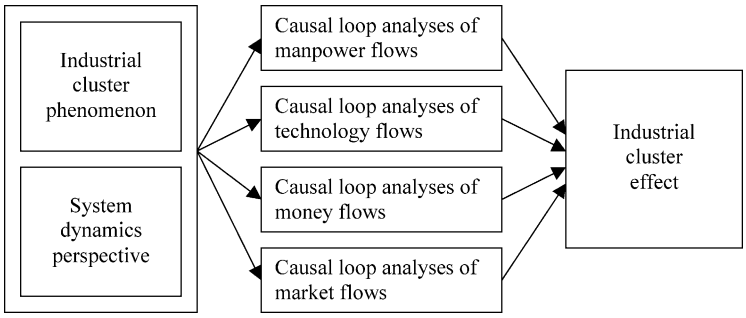

Fig. 2. Conceptual framework of this research.

the industrial cluster effect were divided into four flows: manpower, technology, money and market. A causal loop diagram for each area was then established. The analyses of the causal loop diagrams helped identify the influential factors and features of industrial clusters effect, and thereby, assist enterprises in strengthening global competitive advantage.

4. Competitive advantage achieved by industrial clusters

Industrial clusters improve competitiveness by increasing in both interorganization and industrial productivity, advancing innovation capability and urging new enterprise formation.

4.1. Industrial clusters and productivity

Industrial clusters' increased productivity is a result of the following conditions: (1) Close proximity to professional human resources and components: the important features of industry clusters are external economies, generalized reciprocity and flexible specialization (Dayasindhu, 2002). Industrial location theory states that the cost savings that result from spatial concentration are a major force in the creation of industrial clusters. Cost savings generally result from increased market power, availability and use of specialized facilities, and shared physical and human infrastructure (Dayasindhu, 2002). Specialized firms can provide cheap and high-quality products, thus reducing operating risks when serving diversified customers. (2) Close proximity to information: the existence and effects of knowledge spillover as sources of innovative output and productivity growth are an important research issue in the economics of technology (Baptista and Swann, 1998). Innovation activity and output are closely associated with firm entry and productivity growth, as shown by Geroski (1991, 1995). Jaffe et al. (1993) explore the extent to which spillovers associated with R&D activity is geographically localized, thus significantly influencing the clustering process. Industrial centers therefore, generate more knowledge spillover, and more innovative output. (3) Complementary relationships among industries and complete infrastructure: clustered firms are more generated and reinforced by a positive feedback process based on customer-service-based advantages, including delivery service, product design, whole management and after-sales service, as well as advancing overall service quality and efficiency. Sophisticated buyers can be developed through meeting customer requirements and rapidly obtaining diversified products from providers. As a cluster's scope broadens, public government is more willing to invest in infrastructure. (4) Competitive pressure: the co-competition relationship among cluster members is the spur for surpassing the competitors and reducing firm's monitoring costs. Firms also will self-requests and reduce speculative behavior to maintain goodwill. As already noted, the industrial cluster effect motivates productivity.

4.2. Industrial clusters and innovation capability

The reasons that industry clusters promote innovative capability include the following. (1) Giving firms access to new components: component providers possess both various customers and diversified products possess innovative ability. Cluster firms clearly understand customer needs and efficiently provide customers with satisfactory products and services. Firms can access new parts, services, machinery and other elements for executing the innovation. (2) Reduce experimental costs: due to the large customer base and new technological information within clusters, enterprises can easily recognize market opportunities to investment in new products or services, develop new manufacturing processes and reduce cost and risk. (3) Make differentiation as the motivator of innovation: a geographical cluster is defined as a strong collection of related companies located in a small geographical area, thus resulting in strong competitive pressure among enterprises. Both sustained innovation and differential products are important sources of firm competitive advantage, industrial clusters can drive innovation forward.

4.3. Industrial clusters and new enterprise formation

The motivational powers of new businesses to move to an industrial cluster include the following. (1) Ease of obtaining market information: market information is easily accessible in clusters and the disadvantages of products, services and supply chain can identified and adopt correct action immediately. (2) Low entry barriers: it is easier to obtain outstanding professional personnel and components, as well as technical and fundamental base construction support, and consequently diminish the investment risks for investors and banking institutions. Perhaps industrial clusters thus represent a market for conveniently developing a new business.

5. Definitions of modeling factors

The procedures in SD modeling include (Roberts, 1978): (1) problem recognition; (2) problem understanding and system description; (3) developing a formal model and computer simulation; (4) illustrating consequences and system correction; (5) identifying and determining the best policy. This study defines models of manpower, technology, money and market flows as follows:

(1) Manpower flows: these flows begin with the industrial cluster effect and use human resources as the main field, such as professional demand, channel and speed of personnel training, number of high quality human

resources, etc. and thus expand the industrial cluster effect.

(2) Technology flows: these flows begin with top technology and use it as the main field, such as technology spillover, knowledge resources, entrepreneurial technological level and entrepreneurial competitive strength.

(3) Money flows: these flows use entrepreneurial financial operations as a main field, such as substantial investment fund, loan desire of banking institution, funds raising ability and entrepreneurial usable fund.

(4) Market flows: these flows use the distribution and scope of a market and supply-demand relations as the main field, such as the attractiveness of regional concentration, the completeness of related and supporting Industries, the specialized ability of suppliers, market potential capacity and industrial scale.

This study divided the phenomenon of industrial clusters into four different dimensions of flows according to the SD perspective, and formed separate causal loop diagrams. The entire causal loop diagram was finally composed of the connection among these four causal loop diagrams.

6. Establishment of a causal loop diagram

As stated, this study divided the causal loop diagram of industrial clusters into manpower, technology, money and market flows.

(1) Manpower flows of industrial clusters: human resources are an important factor of forming industrial clusters. Numerous professionals have undoubtedly been gathered within clusters. Therefore, R&D institutions like universities and public and private research centers play significant roles in providing multi-channels of personnel training, thus satisfying the requirements of specialized training, education, information and technology support. By improving human resource quality and advances in entrepreneurial innovation ability, the competitive advantage of industry is promoted, opportunities are created for new industries, and the attraction of industrial clusters is increased. As shown in the positive feedback loop in Fig. 3, the continuous spread of the industrial cluster effect is restrained because of the interference from requirement of professionals and number of research institution. Professional demand is restricted on personnel training speed and number of research institution is limited by restriction on government's resources. The slow action of long cultivated time results cannot save a critical situation.

(2) Technology flows of industrial clusters: technology is the other key factor in industrial clusters. Clusters are characterized by technology spillover, and also contain numerous research institutions, resulting in abundant knowledge resources, and therefore, advancing entrepreneurial technological level. Technological progress reduces costs and benefits both competitiveness and profitability. Opportunities for cooperation increase among firms so as to expand the scale of production, still more urge the industrial cluster effect. As shown in the positive feedback loop in Fig. 4, the continuous spread situation of the industrial cluster effect is restrained owing to the interference points of the number of research institutions and the entrepreneurial technological levels. The number of research institutions are restricted by limited government resources and firm technology level is strongly affected by firm internal environment such as rich knowledge resources, employee knowledge levels and the degree of coordination of managerial strategies. The desire to develop

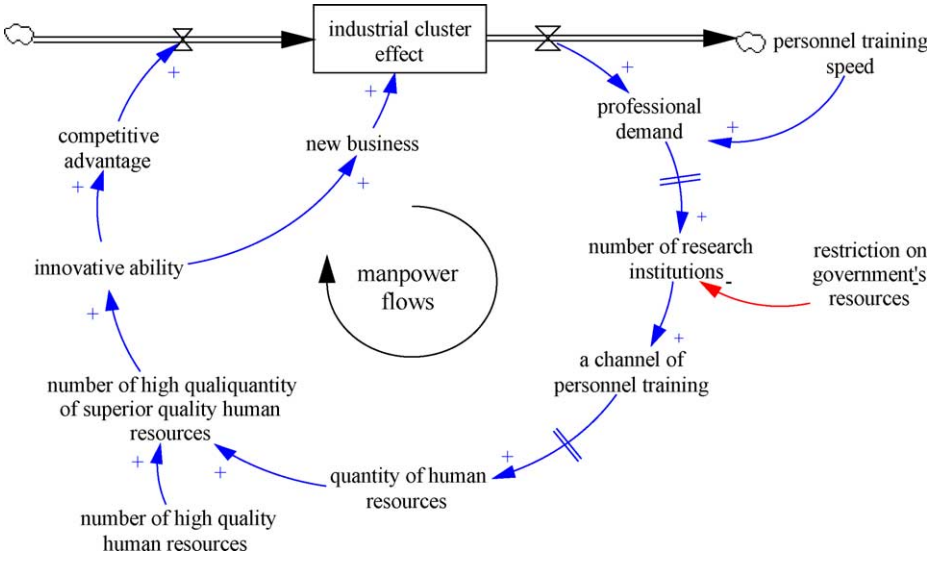

Fig. 3. Causal loop diagram of manpower flows.

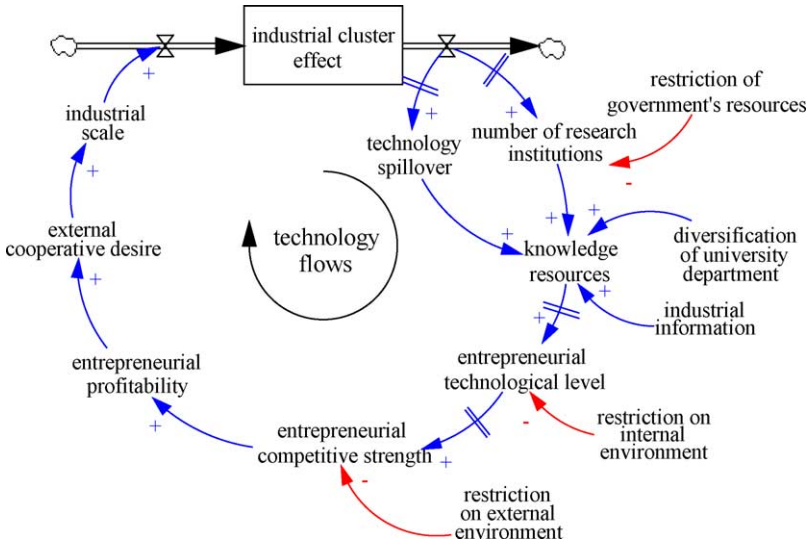

Fig. 4. Causal loop diagram of technology flows.

new techniques will reduce if techniques can acquired easily.

(3) Money flows of industrial clusters: the ease of cluster formation implies a good investment environment. Investment attractiveness increases with the integrity of the entire investment environment, including completed material flow systems, infrastructure and completed regulation and tax laws. Increased investment can boost productivity and strengthen both the credit and reimbursement ability of enterprises, enabling enterprises to easily obtain loans from banks. Moreover, the increase in usable funds can improve firm's innovation ability and form a new business, and thus gain the industrial cluster effect. A positive feedback loop is shown in Fig. 5. Because it is difficult to raise funds without a limit for a firm and affected by a recession, the attraction of the investment decreases and the extension of the loop is restricted. The interference points of investment attractiveness involves investment cost, and productivity is also affected by restriction on other resources; besides, reinvestment funds are affected by debt ratio, financial risk generally increasing with increasing debt ratio, thus reducing enterprise desire to invest.

(4) Market flows of industrial clusters: the industrial cluster effect is reinforced due to geographical proximity, while the completed related and supporting industry enhance the degree of industrial division of labor. To attract more customers, suppliers must increase specialization and produce more competitive products, and provide

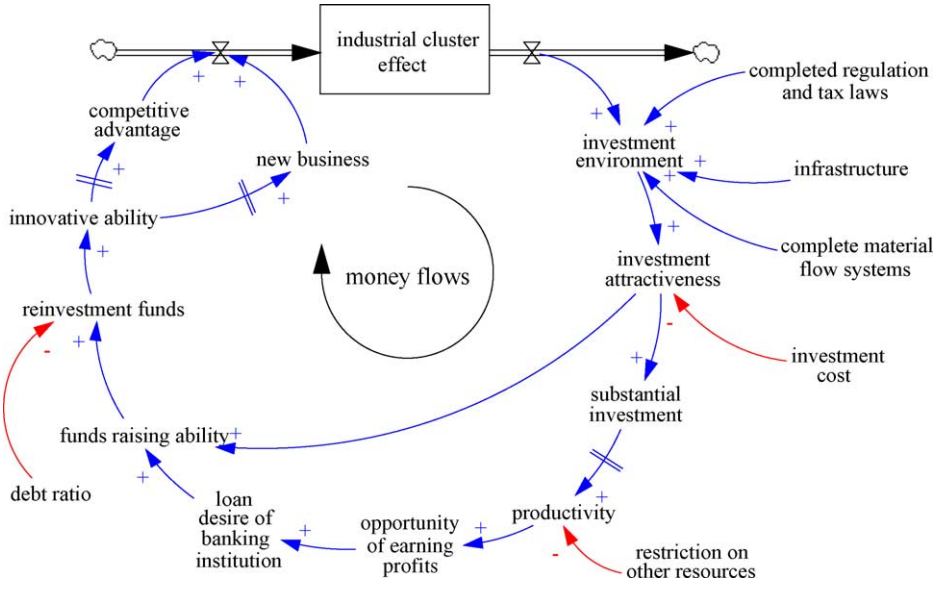

Fig. 5. Causal loop diagram of money flows.

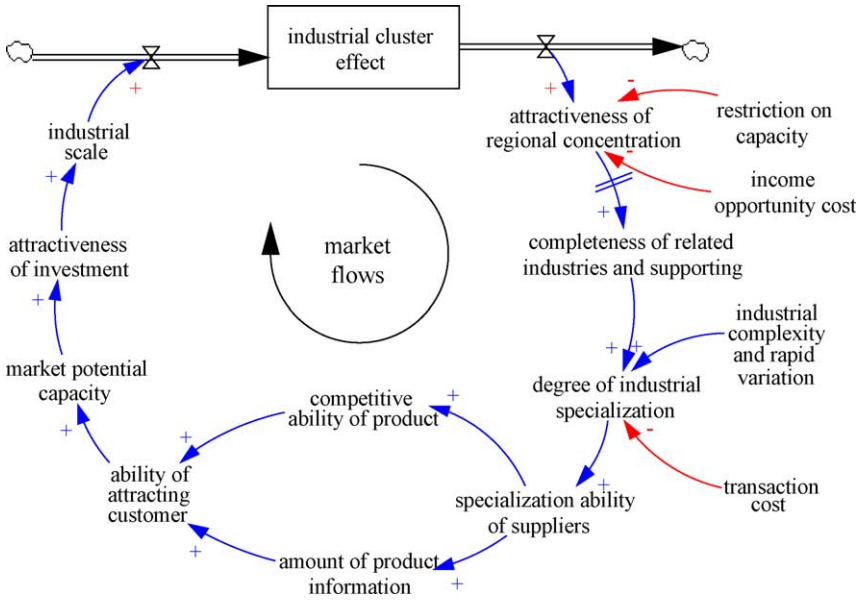

Fig. 6. Causal loop diagram of market flows.

more information. An increased ability to attract customers increases market potential, and thus increases the attractiveness of investment like foreign capital, and therefore, expanding industrial scale. Comprising a positive feedback loop as shown in Fig. 6, the attractiveness of regional concentration is restrained by interference point of the restriction on capacity and opportunity cost. The other interference point is the degree of industrial specialization. Much more transaction costs such as negotiation and contract costs are spent on required to bargain with other entities if the industry in more complex and rapidly varying. The four diagrams described above show how the entire causal loop diagram of the industrial cluster effect is obtained (see Fig. 7).

7. Conclusion and discussion

This study presents a number of conclusions, based on the four causal loop diagrams of the industrial cluster effect:

(1) Both individual and comprehensive causal loop diagrams illustrated positive feedback situations: even so, not all of them expand to resemble a snowball effect without limitations. The causal loops are restrained by the limitations of interference points in the real world. The topic of interference points is worthy of further investigation.

(2) Manpower flows associated with the industrial cluster effect: the industrial cluster effect of flows of manpower is restricted by the demands of professional (or personnel training speed). A government's policy affects the number of research institutions. The professional personnel cultivated by government differ from the realistic demands of industry, resulting in a drop. Additionally, due to professional manpower generally being unable to be supplied instantly, so the demands of profess ional personnel cannot be satisfied owing to delayed supply of manpower.

(3) Technology flows associated with the industrial cluster effect: besides the number of research institutions is affected by government policy guidance, and the enhancement entrepreneurial technological level is also limited because it depends on whether a supportive environment can maintain technological progress. Furthermore, employee quality and quantity must also be appropriately selected, which restricts technology flows.

(4) Money flows associated with industrial cluster effect: money flows are strongly affected by the investment environment, because the investment environment affects investment attractiveness, firms are generally trying to reduce substantial investment during a period of economic recession. Furthermore, the investment attractiveness involves a restriction on investment cost, and affected by the evaluate factors of invest beneficial result like product leadership position, product value and profitability. The reinvestment funds are also limited by the factors related to debt ratio.

(5) Market flows associated with industrial cluster effect: the economic use value of land restrains the attractiveness of regional concentration, because extremely exploitation of a singly area will create side effects such as environmental protection issues and problems in factory expansion. Moreover, the completeness of related and supporting industries is difficult to achieve

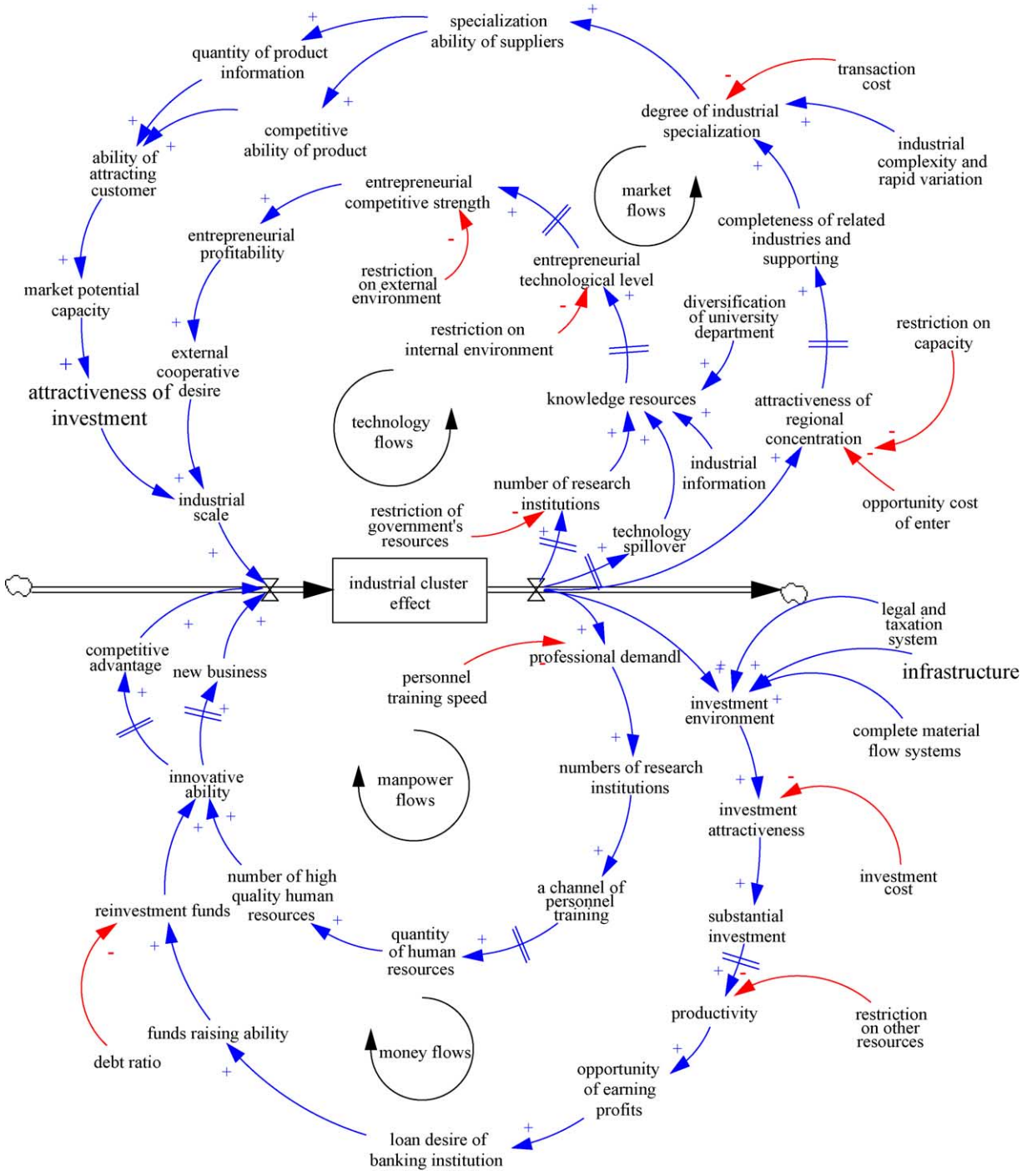

Fig. 7. System dynamics diagram of the industrial cluster effect.

because of the trend of detailed specialized division and the industrial complication, variableness.

In the situation of economic resources moving rapidly, capital liberalization and the convenient information transmission, new forms of competition become a global competitive trend. Focusing on sustaining innovation and strengthening knowledge management may cause the enterprises maintain competitive advantage. Industrial clusters result from the geographic locations of industries. Additionally, the technology spillover effects and knowledge within clusters benefit the formation of new technology and knowledge of firms. Nevertheless, the industrial cluster effect is affected by various factors. This study demonstrated the discussion of the influence factors of industrial cluster effect based on the dynamic aspect of four causal loop diagrams, including manpower, technology, money and market flows. Thus the primary contribution of

this study is using SD perspective to detail the interactive relationships with the four important loops of industrial competition. Therefore, the complex relations involved in the industrial cluster effect can be observed through SD analysis, which is a deficiency of other methodologies. Moreover, the causal loop diagrams in this study provide follow-up researchers who study industrial cluster effect a different aspect. The follow-up researchers also can collect related statistical data and execute simulations to establish simulate procedures and analyze variable affection.

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