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Knowledge patterns and spatial dynamics of industrial districts in knowledge cities: Hsinchu, Taiwan

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ABSTRACT

In the era of a global knowledge economy, urban regions that seek to increase their competitive edge and become destinations for talent and investment have little chance of achieving these goals without forming effective knowledge-based urban development strategies. Hence, the development of clusters of knowledge-based corporations has become an important strategic factor in increasing the competitiveness of knowledge cities. Whereas previous studies have tended to focus on the characteristics of local clusters and the causes of their success, empirical studies of the long-term development of local knowledge-based industries are few. Accordingly, this investigation takes the knowledge city region-Hsinchu as its subject, and quantitatively analyzes the correlation between the spatial dynamics of knowledge in major industries and innovation based on empirical data. This finding shows that steadily developing industries in the Hsinchu region have continued to strengthen their new knowledge of product development and innovation. An overview of innovative activities of firms also revealed that their knowledge patterns have been changing from patterns of internal dependency to a locality-based, broader networking and agglomeration pattern.

1. Introduction

In a growing knowledge economy talent and creativity are becoming increasingly decisive in shaping economic opportunity and knowledge based urban development. Prosperity now depends less on access to physical resources and more and more on the ability to create economically useful new ideas (Yigitcanlar, Baum, & Horton, 2007). In knowledge economy and knowledge based urban development the contribution of knowledge workers and knowledge-based corporations is often mentioned as strategic and valuable (Baum, O'Connor, & Yigitcanlar, 2009; Florida, 2005; Hu, Lin, & Chang, 2013). Most significantly, knowledge-intensive industrial districts are proactively approaching or seeking links with sources of new knowledge production, with the objective of facilitating new knowledge transfer and thus achieving competitive advantage of knowledge cities (Hu, Lin, & Chang, 2005). Accordingly, why some countries or regions experience faster economic growth is difficult to determine and the question has attracted the attention of several researchers and institutions. In answering this question, Porter's (1990) industry cluster theory, presented in his book, "the Competitive Advantage of Nations" is very influential. His core argument is that clustering prompts the flow of goods in a geographically limited region, supporting intensive interactions among services, ideas and skills, supporting technological development, increasing production efficiency, and accelerating innovation. The ultimate effects are improvements in the generation, circulation, diffusion and application of knowledge in a cluster. Hence, a local cluster is characterized by the benefit that is afforded to firms that are located in a region by a particular regional structure and organization, which provides opportunities for innovation and success (Becattini, 1990; Camagni, 1995; Lawson, 1999). Consequently, local clustering enhances the regional knowledge base. It supports companies and startups that are better able to innovate and are more successful than they would otherwise be, thereby reducing unemployment and promoting economic growth.

Most of the pertinent literature considers the existence and emergence of local industry clusters, and the factors that govern their greater success than is achieved elsewhere. It focuses on the reasons for the existence of local clusters. Relatively few studies have examined clusters beyond this initial stage, or focused on the negative effects of local clusters and the reasons for their failure (Grabher, 1993; Isaksen, 2003). Restated, previous studies have not explicitly answered several questions, such as "how long the

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positive effects of industry clusters last?" or "after some time, will a positive effect turn into a negative one?" Clearly, research on the implications of the long-term development of local industry clusters is very limited – and especially weak in the analysis of knowledge patterns and the spatial dynamics of such clusters.

This investigation considers a high-tech industrial district–Hsinchu, which is a knowledge-based urban region.[1] Since Hsinchu Science-based Industry Park (HSIP) is Taiwan's knowledge hub. Besides a huge science and industry park, six universities were established in Hsinchu. This empirical study identifies major industries in the Hsinchu region of HSIP and its surrounding industrial districts by referring to the relevant literature. The study also clarifies what changes this region has undergone. Based on these findings, this study will explain the implications of the long-term development of an industrial district in the framework of knowledge-based urban development, with a special focus on the evolution of knowledge patterns and spatial dynamics.

2. Literature review

In the era of a global knowledge economy, in order to increase their competitive edge and become destinations for talent and investment, urban regions seek to form effective knowledge-based urban development strategies. Hence, the development of clusters of knowledge-based corporations has become an important strategic factor in increasing the competitiveness of knowledge cities. This investigation reviews the literature on the development of an industrial district and dynamic evolution of spatial knowledge, then explores the implications of the long-term development of an industrial district in the framework of knowledge-based urban development.

2.1. Development and evolution of an industrial district

The development of an industrial district is affected by its history, culture, institutional background, and geography. An industrial area depends on interactions among local industries, technology and the environment, and is externally connected via industrial technology to a national or even global institutional environment at (Liu & Wang, 2008). Such an industrial network, based on geographic proximity, is an industry cluster. The development and evolution of an industrial region is rooted in the context of industrial clustering. The literature on cluster theory is extensive. Most studies in the field investigate clustering statically, without observing dynamic changes. Increasing global competition has motivated various studies of such issues as the decline of clusters, their dynamics and their life cycles (Andersen, 2006; Sadler, 2004; Schamp, 2005; De Propris & Lazzeretti, 2009; Menzel & Fornahl, 2009). Some of these studies have found that the transformation of clusters depends on the evolutionary interaction of two dynamics—technological dynamics and regional dynamics. However, the survivability of a cluster in a changing environment depends on its long-term evolution. Crespo (2011) suggested that viability was based on emergence conditions. Different emergence conditions produce differently structured clusters, which therefore confront threats and opportunities with various capabilities.

[1] In the era of the knowledge economy, the development of a city is a complex and multi-faceted phenomenon. To understand it, the concept of knowledge-based urban development (KBUD) has been applied to many metropolitan areas. The purpose of KBUD is to increase competitive advantage; attract talent and investment, and provide prosperity and a high quality of life to residents (Kunzmann, 2008; Yigitcanlar, 2009).

2.1.1. Conditions that affect the viability of industry clusters

Since a cluster has a complex structure and consists of heterogeneous actors who are rooted in a region, as its environment constantly changes, the activities of these actors affect its evolutionary path. In the long run, a cluster may follow various paths. In the absence of significant external impacts, a cluster will remain on a stable development path, strengthening its existing structures and by exploiting its internal process. Another possible path is the decline and ultimate disappearance of a cluster. Such a decline may be caused by the transformation of an internal positive impact into a negative one. It may also be caused by changes in external conditions, such as by the development of new knowledge and technology, policy changes, or the advent of various social and economic events to which a cluster fails to adjust and adapt. Eventually, the decline may cause a cluster to follow the trajectory of reconstruction, forming a new cluster. Internal processes of transformation and the reintegration of any levels of a cluster can contribute to this process (Martin, 2010). Restated, when a cluster is confronted with a constantly changing environment, the long-term evolution of a cluster depends on its viability (Suire & Vicente, 2009).

The viability of clusters as entities that can help local systems cohere is measured in three dimensions (Crespo, 2011). The first dimension emphasizes technology and local capacities. This begins when any new adopters are more willing than previous decision-makers to exploit similar technology or regions mainly to increase effectiveness and profitability. The second dimension is the ability of a cluster to adapt to various threats and to exploit opportunities: this can also be thought of as the ability to transform from the status quo to new technological realities, and to reconstruct regional conditions. The final dimension is the ability of a cluster to be a driving force for change. Local industry clusters are grounded in solid regional and technical capabilities that reduce potential threats to their profits. The weakening of regional and technical capabilities weakens long-term evolutionary capabilities put up barriers to the dispersing of new technologies and cause difficulties in the emergence of new industrial districts. Different regional and technical capabilities result in different survival and absorption capacities of industry clusters, whose long-term evolution depends on their ability to adapt to technical and regional threats or opportunities. The intensity of regional and technical processes depends on exogenous and endogenous factors (Crespo, 2011; Suire & Vicente, 2009). Since effective endogenous innovation depends on intensive interactions, the network model has a significant role in evaluating viability.

2.1.2. Evolution of industry clusters

Various scholars in the field of the evolution of local industry clusters have differently defined the evolutionary lifecycles of those clusters. Porter (1980) first proposed the concept of the industry lifecycle. He divided the industry life cycle into introduction, growth, maturity and decline. He characterized the introduction stage by its high degree of uncertainty. In the growth stage, competition among manufacturers increases and technology provides the main basis of competition. Decline is mostly caused by external environmental factors. Klepper (1997) and Dybe and Kujath (2000) simplified the industry life cycle into three stages, the first stage is birth, which is followed by growth, which is followed by maturity. Hill and Jones (2001) added a turbulence stage between the growth stage and the maturity stage to yield a total of five stages—introduction, growth, turbulence, maturity and decline. They noted that competition became more intense during the turbulence stage owing to the very large number of competitors, but that demand in this stage was lower than in the growth stage. In each stage of the evolutionary cycle, an industry exhibits different characteristics. The development and evolution of an

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entire industrial region are affected not only by internal factors but also by numerous external effects. The changing environment of an industrial area affects its evolution. In the decline stage, industries require an injection of new energy, knowledge or technology to transform (Martin & Sunley, 2006). In the transition stage, stimulating factors critically facilitate the evolution of an industry to the next stage. As Belussi and Sedita (2009) noted, an industrial region frequently follows an evolutionary path from the initial stage to the growth stage, and then to maturity, stagnation, and decline or reinvigoration. Regions that evolve successfully generally demonstrate a capacity for innovation and mechanisms to absorb new knowledge and learn, which allow them to withstand negative external impacts and turn them into new opportunities for growth.

2.2. Dynamic evolution of spatial knowledge

"Knowledge" has always been a crucial resource for shaping and maintaining strong economic, social and cultural development. In the knowledge economy, knowledge-related activities, including innovation based on tacit forms of knowledge, have become critical to the creation of jobs and wealth and the maintenance of economic growth (Ofori, 2003). Sustaining contemporary economic activities requires periodic renewal of the labor force, organizational capacity, and the creation of supportive environments that foster the growth of creativity, innovation, learning and reform (Knight, 1995). Based on this theory, scholars usually regard knowledge not only as a core element of economic development, but also as a core element in social and knowledge-based urban development (Yigitcanlar, O'Connor, & Westerman, 2008; Yigitcanlar & Velibeyoglu, 2008).

2.2.1. Impact of knowledge flow on development of metropolitan regions

The development of the knowledge economy, globalization and the pressures of international competition has increased the importance of creativity and innovation in local economies (Baum, O'Connor, & Yigitcanlar, 2009; Porter, 2001). Accordingly, in recent years, knowledge has been widely investigated in the literature on local industries or knowledge-based urban development. Breschi and Lissoni (2001) noted that the so-called cluster effect arises from the great advantages that firms in a certain area have in the transformation of knowledge. Such advantages improve organizational learning and collective learning in companies and accelerate the creation, accumulation and exchange of various types of specialized, tacit and specific knowledge. Eventually, these are manifest in new product development, process improvements and innovation performance (Hu, 2008; Hu et al., 2013; Wu, Lee, Chen, & Ho, 2012). Generally, in studying the dynamic generation of knowledge and its application in an industrial region, relative continuity and accumulation should be considered (Crevoisier & Jeannerat, 2009). In fact, a regional context (including social, cultural, economic, institutional and other contexts) passes through cycles of agglomeration and accumulation. Its goal is to ensure that the generated knowledge is as well matched as possible to the demanded applications of knowledge. Therefore, the competitiveness of a metropolitan area depends strongly on the cohesion between the application and generation of internal knowledge in an industrial district. Furthermore, fiercer competition in a metropolitan region requires that the formation of a high-quality labor force is more important to its competitiveness. Hence, "resource knowledge" gradually becomes the factor that determines the location (Cooke, Davies, & Wilson, 2002; Faulconbridge, 2008). However, the global distribution of sources of knowledge is extremely uneven, especially when issues that are related to the number and quality of scientific institutions such as universities and research institutions, knowledge accessibility, and professional embeddedness and localization, are considered. This non-uniform distribution of knowledge reveals the increasing importance of knowledge flows to urban and regional development.

Cities initially form as places for exchanging goods and money, but the production of these goods and the development of a city depend strongly on knowledge. Today, many modern knowledge cities have become platforms for specialized activities that involve the production and exchange of knowledge, networks, and material goods. During the last few decades, cities have become key platforms of collective intellectual capital that shape and influence human capital. Collective intellectual capital is a major stimulating factor in knowledge generation and innovation (Edvinsson, 2010). Therefore, in the knowledge era, the local economies of cities must be transformed to be in line with the global knowledge economy. Meanwhile, knowledge-based development has become increasingly important in enabling industrial regions to remain competitive and their associated cities to succeed in global competition and connect with the world.

2.2.2. Trends toward a more diverse evolution of spatial knowledge

The mitigating effect that distance has on the flow and transfer of knowledge has gradually declined. Hence, with the increasing mobility of information, knowledge and talent, societies that are based on traditional industries that are centered on the production of goods and labor have gradually declined, and structures have been formed than enable cultural and natural resources to be deployed economically to respond to these changes. However, these changes do not affect all of paces and all of activities simultaneously. Currently, economic actors have easy access to most highly dispersed knowledge regions, but the actors must identify and activate resources in a converging business environment. Based on this theory, knowledge-based development is based on interdependent choices. The selection is relied on the existing network, and the network system is located in a knowledge cluster that is connected through technological spillover, non-transactional interdependence, or cross-market cluster actors (Fleming & Marx, 2006). Accordingly, actors in a knowledge cluster tent to move along a superior technical path (Storper, 1995). However, a knowledge cluster is just like a product, which has a few evolutionary stages. Through innovation, clusters can revitalize themselves to develop a new pattern and capacity, and evolve to improve competitiveness.

As previously described, the core problem is not simply the generation and use local knowledge, but rather, the lack of strategies for applying local cluster knowledge. Some knowledge regions have developed a strong capacity to integrate and apply distant knowledge (Simmie, 2003). As Crevoisier and Jeannerat (2009) showed, knowledge cities have become "gathering places for clusters" because they are no longer limited to using particular knowledge systems or sub-clusters within cities. Through a variety of activities that enable the solidification of flowing knowledge, a knowledge city can also become a nucleus in the overall spatial dynamics (Simmie & Strambach, 2006). Therefore, this will conduct empirical research to examine the long-term evolution of knowledge patterns and spatial dynamics of an industrial district by applying the concept of knowledge-based urban development.

3. Hsinchu region: Taiwan's knowledge hub

Hsinchu Science-based Industry Park (HSIP) is Taiwan's knowledge hub. In 1980 the government of Taiwan decided to develop this former fishermen village and central place in a mountainous agricultural county as a center of knowledge (Fig. 1). Besides a huge science park, six universities were established, nearly one million inhabitants in Hsinchu City and County. In 2012, the park

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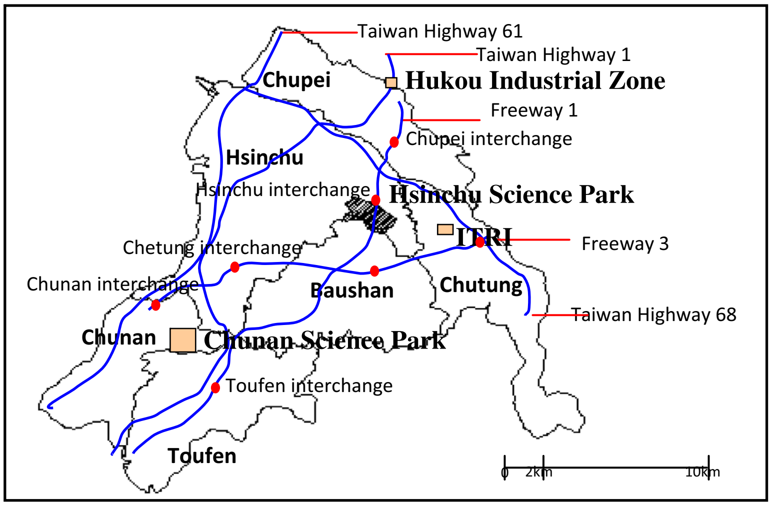

Fig. 1. Hsinchu: location and major infrastructure and urban characteristics.

accommodated 477 enterprises, with more than 151,000 jobs and approximately annual sales of US$ 40 billion. Over 75% of employees in the Hsinchu Science Park held at least the Junior college, and 2.1% of employees had doctoral degrees. At present, the HSIP covers six locations—the Hsinchu, Zhunan, Tongluo, Longtan and Yilan parks as well as the Hsinchu Biomedical Science Park. Most enterprises are manufacturers involved in integrated circuits, optoelectronics, computer and peripherals, telecommunications, and precision machinery. The Industrial Technology Research Institute of Taiwan (ITRI), located near HSIP, provided government support during its embryonic stage. HSIP grew particularly rapidly from 1991 to 2000. This period saw annual sales grow twelve fold, the number of companies double, and the number of employees quadruple.

Approximately 25% of the 171 companies added during 1990 to 1999, the most rapid period of growth and expansion of HSIP, were spin-offs created through this knowledge infrastructure. The level of comprehensiveness of a supporting environment facilitated the formation and the survival of numerous spinoffs or start-ups formation, and strengthened regional self-growth. Thereby KIBS acts as a critical interface in creating a comprehensive supporting environment for self-growth. Additionally, out of the 21 companies successful incubated by the ITRI Incubator from 1997 to 2001, 60 percent chose to locate in the Hsinchu (including HSIP). Of the 30 successfully incubated companies from 2002 to 2006, (nearly 80% located in the Hsinchu (including HSIP). By 2009, over 80% of the 94 successfully incubated start-up companies chose to locate in HSIP or near ITRI and HSIP. This phenomenon demonstrates that spin-offs of start-up companies instigate the continuous local diffusion, accumulation, and re-generation of new knowledge. Thus, professional trained or start-up companies incubated by ITRI or related universities chose to locate in HSIP or nearby, crossing the spatial boundaries of the Hsinchu cluster and related industries to continue to expand outwards.

Additionally, modern residential quarters, international kindergartens and schools were built in the precincts of the park to attract knowledge workers from Taipei and even Taiwanese experts from the US and other countries. Under this situation, regional spatial growth not only exhibits outwards geographic expansion of population and housing owing to transportation accessibility, but is also influenced by pull effects of spatial proximity with internal social and identified proximity as key factors (Kunzmann & Hu, 2013).

4. Research design and data collection

As discussed above, the research literature in this field has been limited of its exploration of the implications of the long-term development of local industrial regions, and especially of their knowledge patterns and spatial evolution. This empirical investigation concerns a high-tech industrial district, the Hsinchu region (including Hsinchu City and County). The Hsinchu metropolitan area not only includes a science park that is over 30 years old, but also includes a knowledge city that was formed by knowledge-based urban development. This study will identify major industries in the Hsinchu region using the relevant literature, and clarify changes that have occurred in this industrial district over time. Based on these findings, this study will explain the implications of the long-term development of an industrial district in the framework of knowledge-based urban development, with a special focus on the evolution of knowledge patterns and spatial dynamics.

First, location quotients are utilized to quantify the industrial development of Hsinchu; then, a statistical analysis is carried out to determine whether Hsinchu's major industries have significantly changed, and if so, how, and to identify the connections between spatial evolution and innovation activities, determining the types of knowledge networks that currently exist in Hsinchu and how these have changed. The research methods that are primarily used in this investigation are as follows.

a. To elucidate industrial development in the Hsinchu region, the location quotient method (LQ) was used to analyze industrial structures therein,[2] where Ei is the regional employment in industry i in year t, E the total regional employment in year t, Ni the national employment in industry i in year t, and N the total national employment in year t. The location quotient can be used to quantify the degree of specialization and concentration of regional industries. The results will serve as the basis for subsequent analysis.

[2] This technique compares the local economy to a reference economy, in the process attempting to identify specializations in the local economy. The location quotient technique is based upon a calculated ratio between the local economy and the economy of some reference unit.

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$$LQ = \frac{Ei}{E} \bigg/ \frac{Ni}{N} \quad (1)$$

b. Analysis of variance (ANOVA) is utilized to investigate changes in the major industries in the Hsinchu, and then a curvilinear regression analysis is conducted to examine and explain the dynamic evolution of major industries in the Hsinchu, with reference to Brenner's (2004) proposed theoretical model of local industrial clusters.
c. Simple logistic regression analysis is used to elucidate correlations between the spatial evolution and innovation activities of major industries in the Hsinchu and to identify changes in knowledge patterns of industries in the context of the spatial evolution and innovation activities of the industries therein.

Data from the 1996, 2001 and 2006 Taiwan Industry, Commerce and Service Censuses were utilized to determine changes in the number of firms, employment and location quotients in the Hsinchu. Regression analyses were performed to interpret the changes in the industry dynamics. The correlation between the spatial evolution and innovation activities of industries was elucidated using a database that was established as part of the Second Industrial Innovation Survey in Taiwan, which conducted by Taiwan's National Science Council in 2007, with the purpose of elucidating industrial knowledge patterns and their changes in the context of spatial dynamics and innovation activities.

5. Results

5.1. Industrial development in the Hsinchu region

In this study, numbers of employees from the Taiwan Industry, Commerce and Service Censuses were used to calculate the location quotients of industries in the Hsinchu district.[3] Numbers of employees in industries with three-digit codes and some with four-digit codes in the Standard Industrial Classification (SIC) of Taiwan were considered. The results reveal that electrical and electronic machinery and equipment manufacturing employed the most people in the Hsinchu region in 1996. By 2001 and 2006, computer manufacturing, telecommunication and audio-visual electronic product manufacturing, electronic component manufacturing, and electrical machinery and equipment manufacturing employed the most people. This finding shows that industries have become more diversified in the Hsinchu region. The results also indicate that the Hsinchu region has become more specialized in high technology than has the rest of the country. Meanwhile, various related high-tech industries have emerged, including the semiconductor industry, optical materials and components manufacturing. This investigation also found that these industries experienced considerable development in recent years and gradually growing and converging to become important industries in the Hsinchu region.

Location quotients were used to understand changes in technology industries from 1996 to 2001. The rapid rise of the semiconductor industry from 1996 to 2001 stimulated the development of the Hsinchu region and related industries therein. HSIP experienced two decades of steady growth from 1980. Its management was devoted to competing with foreign science parks and actively improved the investment environment, helping technology industries to develop steadily (Taiwan National Science Council, 2002). Although the mean location quotient fell in 2006, the district was home to a diverse range of industries. A large fraction of the work force was not employed by a single large industry, but was employed by many sub-industries in a major industrial sector or collaborating industries.

Table 1
ANOVA of location quotients of major industries in Hsinchu.

	LQ 1996 Average ± S.D	LQ 2001 Average ± S.D	LQ 2006 Average ± S.D
Local Industries	2.27 ± 3.13[a]	1.79 ± 1.98[b]	1.48 ± 1.68[c]

Note: The study used one-way ANOVA, repeated measures to conduct test, and $\chi^2 = 11.373$, $F = 4.415$, and a, b and c denote $p < .05$ with significance.

5.2. Defining major industries in the Hsinchu region and change thereof

To identify changes in the major industries in the Hsinchu region, the 2006 Taiwan Industry, Commerce and Service Census was used to provide a benchmark. Two-digit codes industries, with location quotients greater than one, were selected, and the presence of firms in all 52 subcategories of these Two-digit codes industries was analyzed. Two-digit codes industries not only include high-tech manufacturing but also computer system design services, construction, engineering services and technical testing, analysis services, employment services, and buildings and landscaping services. Even though local basic sectors dominated the Hsinchu region from 2001 to 2006, high-tech-related manufacturing has slowly become a major industry in Hsinchu. Support services and professional, scientific and technical services have also become important industries in the Hsinchu region, revealing the increasing demand for, and importance of, supporting industries, including knowledge-intensive services, as high-tech industries have developed.

5.2.1. ANOVA of evolution of major industries

To elucidate the evolution of the 52 major industries in Hsinchu, ANOVA (one-way ANOVA, repeated measures) was conducted on their location quotients in 1996, 2001 and 2006, respectively. The results (Table 1) reveal significant variation in the location quotients of the major industries in Hsinchu among the years 1996, 2001 and 2006 ($p < 0.05$). Major industries in the Hsinchu region, including basic industries, high-tech industries and knowledge-intensive industries, underwent considerable changes from 1996 to 2006. Thus, this study preliminarily concludes that the major industries in the Hsinchu region have undergone significant evolution, and it further investigates how their capacities to evolve have changed, their mechanisms of evolution, and their relationship with the environmental and industrial backgrounds of the Hsinchu region.

5.2.2. Analysis of spatial dynamics of major industries

The location quotient analysis and ANOVA provide a preliminary understanding of changes in the major industries in the Hsinchu region over the last 15 years. This section draws on the theoretical model of local industry clusters that was developed by Brenner (2004), in which the local industry clusters evolve through four stages and the number of companies therein changes as they grow.[4]

[3] This investigation included some industries with four-digit codes primarily because of various revisions of the Standard Industrial Classification of Taiwan over the last 15 years, including its sixth version in 1996, seventh version in 2001, and eighth version in 2006.

[4] Brenner (2004, p.39) divided the evolution of local industrial clusters into four stages. The first stage is characterized by predictable increases in the number of companies in all regions. In the second stage, self-growth, results in variation among regions. Some clusters evolve as industry clusters and some emerge as non-clusters. The third stage is characterized by a fairly stable state, with only a few fluctuations in number of firms. The fourth stage is the disappearance of clusters, generally as a result of diminishing market demand for goods.

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Table 2
Dynamic patterns of major industries in Hsinchu.

SIC code	Industries	1996–2001	2001–2006	1996–2006	Industrial dynamics
18	Chemical material manufacturing	Other	Equilibrium	Other	Equilibrium
19	Chemical products manufacturing				
23	Non-metallic mineral products manufacturing	Other	Other	Equilibrium	Equilibrium
25	Fabricated metal products manufacturing	Other	Other	Other	Other
26	Electronic parts and components manufacturing	Other	Other	Other	Other
27	Computers, electronic and optical products manufacturing	Other	Other	Other	Other
28	Electrical equipment manufacturing	Other	Other	Other	Other
29	Machinery and equipment manufacturing	Other	Other	Other	Other
M	Professional, Scientific and technical services	Other	Other	Other	Other
N	Support services	Other	Equilibrium	Other	Equilibrium

In this study, curvilinear regression analysis was conducted on empirically determined changes in number of firms in Hsinchu over time. The Hsinchu region is the center of high-tech manufacturing industry in Taiwan. The demand for knowledge-intensive services is as important as high-tech industrial development. Hence, major industries in Hsinchu that are of interest in this investigation are chemical materials and chemical products manufacturing, non-metallic mineral products manufacturing, electronic components manufacturing, computer, electronic products and optical product manufacturing, electrical equipment manufacturing, support services, and professional, scientific and technical services.

To obtain a statistically significant sample size, the numbers of companies in the aforementioned ten industries in 1996 and 2001 were treated as mutually independent variables. The dependent variables were changes in the numbers of companies from 1996 to 2001, 1996 to 2006 and 2001 to 2006. A curvilinear regression analysis was carried out on every industry and every time period. Based on Brenner's theory, the results of such a regression must be converted into a predictive format using regression coefficients. The regression coefficients can be used to define states of dynamic change of an industry. Three states are thus defined; these are cluster formation, equilibrium, and other (Brenner, 2005, p.931).

Since a regression result is obtained for each industry in each timeframes, analyses are conducted continuously until each industry is assigned a state. The "cluster formation" state is identified when at least one regression result reveals cluster formation, and no result indicates equilibrium. The "equilibrium" state is identified when at least one regression result reveals equilibrium and none indicates cluster formation. The "other" state is identified when results support both cluster formation and equilibrium, or three regression analyses all supported the classification, "other". The results (Table 2) demonstrate that the changes in the numbers of companies in industries that were classified as "equilibrium" were more balanced and stable over the time frame of this study than were those industries that were classified differently, and the spatial distribution of companies tended to be more even. From 1996 to 2006, chemical materials and chemical product manufacturing, and non-metallic mineral product manufacturing, were classified as being in equilibrium. The "other" classification indicated a more volatile state with a more dispersed spatial pattern of companies and larger changes in the number of companies present in the region over time. Industries in this state included computer and electronic product manufacturing as well as optical product manufacturing.

The above analysis reveals that regional industries evolved differently from each other over more than ten years. Some industries did not experience many changes over ten or more years, but were essentially static. Hsinchu, the so-called Silicon Valley of Taiwan, became a member of the global high-tech industry network following the development of electronic components, computers, electronics and optical product manufacturing and related industries, which was promoted by the advantages afforded by the semiconductor industry cluster. Despite decades of development, semiconductor industries have continuously failed to be profitable. Based on the empirical results that are presented in this investigation, semiconductor-related manufacturing industries no longer cluster, and have evolved to a status quo. This finding is consistent with the forecast of Hu, Chang, Lin, and Chien (2006).[5] Although the highly competitive semiconductor industries have innovated slightly in recent years, the rapid expansion of innovation resources has increased the importance of controlling knowledge-based related activities. Relevant research has revealed that the semiconductor talent in Taiwan has had innovative ideas, but has failed to transform them into explicit knowledge in a timely manner and thereby preserve it. Consequently, it misses opportunities to convert and apply knowledge effectively (Hu, 2008). The support services industry in Hsinchu has been in decline. High-tech industries have clustered in Hsinchu, seeking new knowledge actively and continuously. Originally, they depended greatly on knowledge-intensive services in the cluster and sought their assistance, but as they became more concerned about trade secrets, knowledge management and related considerations, they began establishing their own foreign or internal knowledge-intensive service departments. Relevant empirical studies (Hu et al., 2013) have noted that even though many companies are classified as manufacturers, they have increasingly created internal departments with knowledge-intensive service functions. As these firms did so, the demand for support services in the Hsinchu region slowly declined.

Based on the above findings, whether it's to grasp and exploit knowledge-based activities or convert to functions of knowledge-intensive services, have both prompted changes in industries that manifest in different states, including "equilibrium" or "other". Therefore, during spatial evolution, the flow or transformation of knowledge may affect these development patterns. The next section will use simple logistic regression to examine the correlations between industries in "equilibrium" or "other" states and innovation, to analyze further the transformation and impact of knowledge patterns.

5.3. Analysis of innovation activities of major industries in Hsinchu

This section elucidates the correlations among the spatial dynamics of regional industries and innovation and local collaboration. The main purpose is to determine whether different industry dynamics result in different innovation capacities and local collaboration? Analyses of empirical data from the Hsinchu region did not reveal one of the above three "cluster" patterns. Accordingly,

[5] New firms tend to cluster in the Hsinchu region. On maturity, around 40% of these corporations are likely to expand further in Northern Taiwan during the next 3-5 years. After 5-8 years, some firms may even go outside their current cluster and form links with other clusters, especially cross-board clusters in mainland China (Hu et al., 2006).

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Table 3
Industrial dynamics and product innovation.

Industrial dynamics	Product innovation		Service innovation	
	YES (%)	NO (%)	YES (%)	NO (%)
Equilibrium	25.9	46.7	28.6	39.5
Other	74.1	53.3	71.4	60.5

only "equilibrium" and "other" patterns were analyzed. In the simple logistic regression analysis, the independent variables were industrial innovation and local cooperation, and the dependent variables were identified by the analyses of industry dynamics that were discussed in the preceding section.

5.3.1. Dimensions of industrial innovation

This section discusses correlations between industry dynamics and four variables: product innovation, percentage of turnover invested in innovation, process innovation, and percentage of turnover invested in technological innovation.

5.3.1.1. Product innovation. Product innovation, as defined in Taiwan's Industrial Innovation Activities Survey, includes innovation in goods and services. Overall product innovation and industrial dynamics were significantly correlated, according to the chi-square test ($\chi^2 = 6.418$, $p < 0.05$). A simple logistic regression analysis further indicated that the industries with the "other" pattern of dynamics were significantly positively correlated with their degree of product innovation. Industries in "equilibrium" demonstrated a negative correlation (Appendix 1). Table 3 shows that industries on the "other" pattern exhibited greater innovation of both goods and services than those in the "equilibrium" pattern. This result indicates that innovation is important to maintaining the competitive advantage of companies on which their survival depends. Industries in the "other" pattern focused more on product and service innovation. They are committed to increasing their corporate value to remain competitive. Industries in the "equilibrium" pattern were in decline, and less able to maintain or gain capacity to innovate.

5.3.1.2. Percentage of total turnover invested in product innovation. The chi-square test[6] revealed a significant correlation ($p < 0.05$) between the percentage of total turnover invested in product innovation and industry dynamics. A simple logistic regression analysis revealed that the percentage of the total turnover invested in production innovation for industries with the "other" pattern of dynamics was significantly positively correlated. Industries with dynamics in the "equilibrium" pattern exhibited a significantly negative correlation (Appendix 1). Table 4 also demonstrates that 55.4% of industries with dynamics in the "other" pattern invested more than half of their total turnover in product innovation activities—more that invested by industries in the "equilibrium" pattern (33.4%). This result confirms that innovation capacity is crucial for companies to stay competitive.

5.3.1.3. Process innovation. The chi-square test revealed the absence of a significant correlation between process innovation and industry dynamics ($\chi^2 = 2.174$, $p > 0.05$). Simple logistic regression analysis revealed that process innovation by industries with "equilibrium" dynamics varied negatively—i.e., the degree of innovation declined, while that of industries with "other" dynamics varied positively. However, these variations were not significant. Product innovation depends on the use of significant resources so most companies focused more on internal process innovation, which they better controlled.[7] Even though industries with "other" dynamics did not exhibit a significant correlation between this variable and industry dynamics, their process innovation did change positively over time.

5.3.1.4. Percentage of total turnover invested in technological innovation. A chi-square test[8] did not reveal statistically significant correlation ($p > 0.05$) between the percentage of total turnover invested in technological innovation and industrial dynamics. The simple logistic regression analysis revealed that industries with the "other" dynamics exhibited a positive correlation with the percentage of total turnover invested in technological innovation. Industries with the "equilibrium" dynamics exhibited a negative correlation. However none of these changes was statistically significant (Appendix 1). Moreover, the percentage of total turnover invested in technological innovation was lower than the percentage of total turnover invested in product innovation for industries with "equilibrium" or "other" dynamics, by as much as 36% (Table 5). These results indicate that such companies were committed to process innovation to reduce costs and to product innovation to enhance corporate value. They were able to control process innovation internally, but they could not internally control product innovation, which required more front-end innovation activities. Companies that shifted from innovating processes to innovating products relied heavily on external support. Therefore, industries with "other" dynamics focused more on enhancing their corporate value in order to remain competitive.

5.3.2. Dimensions of local cooperation and sharing

To sustain local industrial clusters, not only must the environment and inputs to innovation be improved continuously, but also local cooperation and the sharing of a network mechanism must be ensured. This study will discuss three actors in local cooperation and sharing—including suppliers, competitors, and local universities—and the correlation of these actors with industrial dynamics.

5.3.2.1. Cooperation with suppliers. The chi-square test did not reveal a significant correlation between industry dynamics and cooperation with suppliers ($\chi^2 = 0.820$, $p > 0.05$). Simple logistic regression analysis also failed to show a significant correlation (Appendix 1). Table 6 reveals that neither industries with "equilibrium" dynamics nor those with "other" dynamics exhibited a high ratio of cooperation with suppliers. However, the results herein support certain conclusions. In the process of supplying goods and services, companies may gather information about their competitors from their own suppliers. To prevent this occurrence, companies avoid cooperating with suppliers in the same region even though frequent interactions with suppliers are necessary. Rather, they chose to cooperate with suppliers at a distance or even across borders (Hu et al., 2013).

5.3.2.2. Cooperation with competitors. According to a chi-square test, no significant correlation ($\chi^2 = 0.235$, $p > 0.05$) existed between industrial dynamics and cooperation with competitors. Simple logistic regression analysis also revealed no significant correlation (Appendix 1). Table 7 also shows the absence of a high

[6] Since the Percentage of Total Turnover Invested in Product Innovation is interval variable, this study used the Pearson's chi-square test to identify the significance.

[7] Technology industry clusters in the Hsinchu region functioned quite effectively in the OEM/ODM era. However, they were not suitable for companies that focused on product innovation. Most of the clusters focused on "process innovation". Product specifications and development processes were mainly provided by client firms. Naturally, industries in the clusters did not have a good grasp of front-end innovation tasks, such as developing, observing and screening new product ideas. Therefore, they relied heavily on external support during their transition.

[8] Since the Percentage of Total Turnover Invested in Technological Innovation is interval variable, this study used the Pearson's chi-square test to identify the significance.

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Table 4
Industrial dynamics and percentage of total turnover invested in product innovation.

Industrial dynamics	Percentage of total turnover invested in product innovation	
	0%–50%	51%–100%
Equilibrium	66.7%	33.4%
Other	44.6%	55.4%

Table 5
Industrial dynamics and percentage of total turnover invested in technological innovation.

Industrial dynamics	Percentage of total turnover invested in technological innovation	
	0%–18%	19%–36%
Equilibrium	94.6%	5.4%
Other	91.6%	8.4%

Table 6
Industrial dynamics and cooperation with suppliers.

Industrial dynamics	Cooperation with suppliers	
	YES (%)	NO (%)
Equilibrium	19	81
Other	16.7	83.3

Table 7
Industrial dynamics and cooperation with competitors.

Industrial dynamics	Cooperation with competitors	
	YES (%)	NO (%)
Equilibrium	9.5	90.5
Other	13.9	86.1

degree of cooperation with competitors in industries with "equilibrium" or "other" dynamics. Cooperation with competitors was less than that with suppliers, revealing that most companies were inclined to be conservative in their business operations. Very few cooperated with competitors to create win–win models, and cooperation was mostly temporary (Hu, 2008).

5.3.2.3. Cooperation with local universities. The chi-square test shows a significant correlation between industry dynamics and cooperation with local universities ($\chi^2 = 6.332$, $p < 0.05$). Simple logistic regression analysis demonstrated a significant correlation (Appendix 1). Based on Table 8, industries with "other" dynamics

Table 8
Industrial dynamics and cooperation with universities.

Industrial dynamics	Cooperation with Universities	
	YES (%)	NO (%)
Equilibrium	9.5	90.5
Other	30.6	69.4

cooperated more with regional universities than did those with "equilibrium" dynamics. Cooperation with universities was especially prevalent in the Hsinchu region. Since universities foster talent, companies can cultivate talent and increase their capacity for innovation by industry–university cooperation, and by establishing better local networks. HSIP, with the support of government, has become energetically innovative by cooperation in with regional universities, such as Chiaotung University, Tsinghua University, ITRI and various national research centers, sharing talent and technology. The internal and external innovative energy of the Hsinchu industrial cluster has continuously increased, propelling its growth. Therefore, the development of regional industries in Hsinchu is closely related to their cooperation with regional universities.

6. Discussion and conclusion

In a growing knowledge economy, prosperity depends less on access to physical resources and more and more on the ability to create economically useful new ideas. The contribution of knowledge workers and knowledge-based corporations is often mentioned as strategic and valuable. Most significantly, knowledge-intensive industrial districts are proactively approaching or seeking links with sources of new knowledge production, with the objective of facilitating new knowledge transfer and thus achieving competitive advantage of knowledge cities. Previous literature has tended to focus on the characteristics of high-tech industrial clusters and reasons for their success. Empirical examinations of the long-term development of local knowledge industries are lacking.

Therefore, this investigation targeted the Hsinchu region as a subject of an empirical study of the spatial dynamics of major industries over the last 15 years, and it examined the correlation between transitioning knowledge patterns and innovation activities. The findings and discussion provide some useful insights for particularly developing countries. Firstly, Major industries in the Hsinchu region exhibited two primary dynamics over the past 15 years—"equilibrium" dynamics, characterized by a steady decline (the clustering of chemical materials and chemical products

Table 9
Results for the logistic regressions.

Variable		Industrial dynamics	
		Industrial dynamics is " equilibrium"	Industrial dynamics is "other"
Industrial innovation	Product innovation	Negative[a]	Positive[a]
	Percentage of total turnover invested in product innovation	Negative[a]	Positive[a]
	Process innovation	Negative	Positive
	Percentage of total turnover invested in technological innovation	Negative	Positive
Local cooperation	Cooperation with suppliers	Positive	Negative
	Cooperation with competitors	Negative	Positive
	Cooperation with universities	Negative[a]	Positive[a]

[a] denotes significance at $p < 0.05$.

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manufacturing, non-metallic mineral product manufacturing, and support service industries, has been falling), and "other" dynamics, characterized by the absence of a continuous strengthening of clusters (industries with close ties to HSIP, including electronic components manufacturing, computer and electronic product manufacturing, and the manufacturing of other optical products, have remained stable.). In determining the causes of these dynamics, knowledge exchange or the evolution of knowledge patterns must be considered as primary factors, and the evolution of industrial spatial dynamics is related to changes in knowledge patterns. Since companies must continuously innovate and introduce new sources of knowledge to sustain their development through the transfer, application and regeneration of knowledge, a lack of knowledge-based activities in the operations of a company can weaken or even eliminate competitiveness. Accordingly, industries with "other" dynamics exhibited a more positive correlation between those dynamics and both innovation and local cooperation than did industries with "equilibrium" dynamics (Table 9). Restated, declining industries used fewer resources in innovation, promoting their decline. Furthermore, in the declining phase, a lack of learning slowed knowledge-based activities and prevented the smooth internal exchange of knowledge. Industries could not innovate effectively and knowledge was not embedded in the region. Therefore, most industries with "equilibrium" dynamics exhibited negative effects on innovative activities. They could not innovate products or processes and did not interact with actors in knowledge flows, further slowing their growth and contributing to their decline.

In contrast, industries with the "other" dynamics continuously expended energy in innovation in order to maintain industrial driving force. In particular, they transitioned to focus on product innovation to increase their corporate value. When their knowledge pattern enabled them to transition internally, they relied greatly on volatile external sources of knowledge, while emphasizing cooperation with neighboring universities to improve their technology and train their personnel. However, the knowledge flow was uncertain. The possible outcome of industries in this stage depends on the abilities of companies to absorb and localize external innovative energy. The attraction, infiltration and diffusion of new knowledge through regions and the strengthening of interactions among various actors in a region to synergize knowledge motivate industries to cluster more, spillover and diffuse. The knowledge pattern transition from internal dependency to broader and more cohesive patterns is rooted in regions. This is becoming more useful to attract corporations and talent, and achieve competitive advantage of knowledge cities, as previous studies mentioned (Hu et al., 2013; Yigitcanlar, 2010; Yigitcanlar et al., 2007).

Based on the foregoing discussion, the spatial dynamics and knowledge patterns in the Hsinchu region are tending to transition into a broader regional networking and cohesive model. However,

Appendix 1

Logistic regression analysis.

Estimates of parameters of product innovation based on innovation based on logistic regression analysis						
Industrial dynamics	B Value	S.E,	Wald	df	Significance	Exp(B)
Equilibrium	−1.441	0.583	6.101	1	0.014	0.237
Other	1.441					
Estimates of parameters that govern percentage of total turnover invested in product innovation based on logistic regression analysis						
Industrial dynamics	B Value	S.E,	Wald	df	Significance	Exp(B)
Equilibrium	−0.015	0.007	4.048	1	0.044	0.985
Other	0.015					
Estimates of parameters of process innovation based on logistic regression analysis						
Industrial dynamics	B Value	S.E,	Wald	df	Significance	Exp(B)
Equilibrium	−0.822	0.562	2.137	1	1.440	0.440
Other	0.822					
Estimates of parameters that govern percentage of total turnover invested in technological innovation based on logistic regression analysis						
Industrial dynamics	B Value	S.E,	Wald	df	Significance	Exp(B)
Equilibrium	−0.107	0.59	3.311	1	0.690	0.899
Other	0.107					
Estimates of parameters of cooperation with suppliers based on logistic regression analysis						
Industrial dynamics	B Value	S.E,	Wald	df	Significance	Exp(B)
Equilibrium	0.163	0.713	0.052	1	0.820	1.176
Other	−0.163					
Estimates of parameters of cooperation with competitors based on logistic regression analysis						
Industrial dynamics	B Value	S.E,	Wald	df	Significance	Exp(B)
Equilibrium	−0.427	0.886	0.232	1	0.630	1.532
Other	0.427					
Estimates of parameters of cooperation with local universities based on logistic regression analysis						
Industrial dynamics	B Value	S.E,	Wald	df	Significance	Exp(B)
Equilibrium	−1.430	0.827	2.993	1	0.048	4.180
Other	1.430					

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knowledge and skills are becoming mobile and integrated, and knowledge patterns that guide industrial changes do not occur in every metropolitan area. The regional environment continues critically to affect patterns of interactions between localities and knowledge flow, which topic is worthy of more in-depth analysis. Additionally, this study attempted to fine-tune and correct constraints that are imposed by the different categories and time frames that are used in various statistical databases. Its analytical results reveal the long-term implications of the development of an industrial district—especially those of the evolution of its knowledge patterns and spatial dynamics—in the context of knowledge-based urban development.

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