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Analyzing Industrial Structure Evolution of Old Industrial Cities Using Evolutionary Resilience Theory: A Case Study in Shenyang of China

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Abstract: The recession and revitalization of old industrial cities concerns urban industrial evolution and its characteristics. Based on the theory of evolutionary resilience, we developed an analytical framework for the industrial structure evolution of old industrial cities, and applied the framework to a case study in Shenyang. The following conclusions are drawn. First, since 1978, Shenyang's industrial growth capacity has shown fluctuation between 'contraction-expansion'. As the secondary industry has a much stronger expansionary and contractionary capacity for growth, this results in lacking stability leading to industrial structure transformation. Second, since 1999, the orientation towards a high-end manufacturing industry in Shenyang has weakened, and the evolution of the new and old growth path is characterized by low-end orientation. Third, since 2007, Shenyang's industrial innovation output capacity has dropped sharply which has been significantly affected by scientific and technological personnel and enterprise-owed science and technology institutions and to a less extent by R&D expenditure. We applied the resilience theory to study the industrial evolution of an old industrial city, explored new study perspectives on industrial evolution and verified the applicability of the resilience theory. This paper provides a scientific reference for understanding the recent deceleration in economic growth in the Northeast old industrial base, and for exploring new paths toward revitalization.

Keywords: evolutionary resilience; industrial evolution path; economic cycle model; old industrial city; Shenyang

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1 Introduction

Evolution in industrial structure has always been a key topic in economics, public administration, and geography (Liu and Zhang, 2016). Studying the evolution of urban industrial structure is of great theoretical and practical significance because experience worldwide has shown that the continuous evolution of industry is one of the most important dynamics in promoting sustained growth of urban economies (Liu and Shen, 2007). Studies on industrial evolution have gone through two historical stages. The first stage mainly involved the evaluation and analysis of changes in industrial structure under the framework of neoclassical economics to reveal the underlying principles (Scherer, 2001), but studies at this stage did not examine the internal mechanisms of industrial structure evolution. The second stage focused on endogenous technological advancement as the driving force of industrial structure evolution, under the lead of 'new growth theory' economists and the idea

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of increasing returns (Romer, 1986). In recent years, evolutionary economics and evolutionary economic geography have moved to the forefront in the study of industrial structure. In evolutionary economic geography, based on the concepts of path dependence and path breaking, industrial upgrading is understood as a path-creation process. It focuses on discussing the influencing mechanism of industrial specialization, industrial diversification and relevant diversity on the formation of new industries and economic growth (Martin and Sunley, 2007).

Most previous studies are based on cases from Europe and America, and the dynamic mechanisms in the formation of new industries with technological interrelatedness as the core process is quite well understood (Frenken et al., 2015). However, there is a gap in the technological innovation abilities of China and that of developed countries, and, therefore whether European and American industrial structure evolution and its mechanisms can be adapted to China requires further investigation. Chinese studies on urban industrial structure evolution focus mainly on the measurement of industrial structure optimization, phase recognition of industrial structure evolution, factors that influence industrial structure evolution, path selection mechanisms, and industrial reconstructing strategies (Dai and Zhou, 2012). Furthermore, studies from the perspective of evolutionary economic geography mainly emphasize the path differences of regional industrial structure evolution in China since the 21st century. They often explore influencing mechanisms of regional industrial evolution in the view of technology relevance and industrial policy to reveal path dependence and path-breaking features (He et al., 2016; Zhu et al., 2017). In general, previous studies are mainly concentrated on resource-based cities and international metropoles including Beijing, Shanghai and Guangzhou, whereas old industrial cities have received little attention (Li et al., 2010).

Since the reforms begun in the 1980s, a small number of leading cities, such as Beijing, Shanghai, and Guangzhou, have achieved an industrial structure with the service sector as their lead. However, most cities in China remain highly industrial, and they attach equal importance to industry and service. Among these cities, old industrial cities which grew rapidly during the first and second Five-Year Plan (FYP) are facing greater challenges associated with industrial restructuring compared with those emerging industrial cities formed more recently (Wang and Wang 2013). Unlike European and American industrial cities which are mostly at the mature stage of 'coping with aging', the majority of old industrial cities in China are still at the stage of 'struggling to grow' (Yang and Yin, 2013). However, after 2011, China's economy began to slow down: the so-called 'new normal', shifting from high-speed growth to medium-high speed growth (Lu, 2015). Influenced by this new macroeconomic environment, the economic growth of Northeast old industrial cities represented by Shenyang declined dramatically. As Shenyang and other old industrial cities still need to maintain a higher growth rate for some time in the future, they are facing much greater growth pressure.

After the global financial crisis of 2008, how regional economies cope with crises and challenges by adapting to volatile external environment has aroused concern and thinking among evolutionary economic geographers on regional resilience issues (Christopherson et al., 2010; Pendall et al., 2010; Pike et al., 2010). Scholars believe that the regional economy in the context of globalization is facing more and more disturbances and crises. To resist the impact caused by the disturbance in economic activities, regional resilience has become one of the most crucial capabilities for achieving regional sustainable development. Regional resilience emphasizes the ability of the region to develop new growth paths, of which path creation is an important dimension of regional resilience. In the existing regional resilience research, evolutionary economic geographers stress that the concept of evolutionary resilience is more theoretical for explaining the prosperity and decline of regional economic activities and industrial structure. We think that these studies on regional resilience provide a new perspective for recognizing economic growth and slowdown in old industrial cities and the relationship between industrial growth and industrial structure evolution. Therefore, we use the evolutionary resilience theory to construct a conceptual model of urban industrial structure evolution characteristics. On this basis, we selected Shengyang City of China as a case study to reveal its industrial structure evolution characteristics since the reform and opening up era so as to provide a scientific reference for understanding economic slowdown in the northeastern region, and for making a new round of strategies for revitalizing Shenyang and other

old industrial cities in China.

2 Theoretical Basis and Analysis Model

2.1 Resilience concept development

The concept of resilience has evolved from engineering resilience to ecological resilience, and then to evolutionary resilience (Shao and Xu, 2015). Compared with engineering resilience and ecological resilience, evolutionary resilience abandons the pursuit of an equilibrium regime, emphasizing that the system is always undergoing complex, dynamic, and nonlinear changes. Resilience is regarded as a kind of change, adaptability and transformation that allows a system to respond to disturbance. New concepts, such as the adaptive cycle theory, were developed under this understanding of resilience. Compared with the previous two conceptualizations, evolutionary resilience has a stronger theoretical persuasion (Walker et al., 2004; Folke, 2006).

2.2 Theoretical basis

Under the concept of evolutionary resilience, the field of evolutionary economic geography is divided into two paradigms: one on the adaptive capacity ability that the regional economy has or reflects when responding to a short-term shock disturbance (Martin, 2012); the other one on the capacity of a new path of regional development to maintain long-term economic development (Boschma, 2015). Most theoretical studies on the former paradigm argue that regional economic resilience is a process involving resistance, recovery, reorientation and renewal under external shocks. Most quantitative empirical studies are based on the global financial crisis and national economic recession as the external disturbance, measuring regional economic resilience and causes for different results from two dimensions: resistance and recovery (Martin et al., 2016). Theoretical studies on the latter paradigm discuss the source of regional creation of new growth paths, mainly investigating influences on regional economic evolution which stem from the correlation between path dependence that is used to maintain the original path of the system to create new path 'adaptation' and path breaking that is used to create the new growth path 'adaptability' (Hu and Hassink, 2017). Most quantitative empirical studies from this paradigm use spatial econometrics to test the influence of industrial diversity, industry-related diversity, institution, external economic links, *etc*., on regional creation for a new path (Frenken et al., 2015; He et al., 2016; Zhu et al., 2017). In qualitative empirical studies, Simmie J and Martin R introduced the adaptive cycle theory to the regional economic resilience study, proposing the 'regional economic resilient four-stage adaptive cycle model', and dividing the regional economic evolution process into exploitation, conservation, release and reorganization. Based on these concepts, they analyzed the economic development and evolution of two cities—Cambridge and Swansea—from 1960 to 2005 (Simmie and Martin, 2010).

While the insights generated by these studies are significant, studies on the theory of evolutionary resilience have yet to produce a complete analytical framework. The field is still in the stage of exploration and perfection (Tan et al., 2017), and it is necessary to develop the theory for practical application.

2.3 Analytical model

Urban economic development is a process of industrial structure evolution. In fact, in the process of evolution, urban industries are affected differently by their macro-economic cycle, industrial cycle, uncertain external impact and 'slow burning'①. Thus, the growth rate of each industry can not be exactly the same. One industry evolution path can be summarized by four typical types (Martin and Sunley, 2011) (Fig. 1a). Since the reform and opening up era began in 1978, the Chinese economy has maintained rapid growth of about 10% for more than 30 years with cyclical fluctuations (Fig. 1b). The Northeast's old industrial cities represented are deeply influenced by the planned economy, and there exists entrenched institutional inertia, rigid economic structures, and other challenges to the regional economy (Zhang, 2016). The industries in Shenyang respond to disturbances stemming from both the macroeconomic cycle and institutional transition. Therefore, the adaptability of industries, that is, resilience of industrial

①Crisis can be divided into two categories, one is the external impact, emphasizing a short-term immediate impact, such as world economic crisis, national economic recession, urban pillar industry recession or move out, unknown competitors appearing, *etc*.; the other one is a long-term, slow and continuous interference, known as 'slow burning', such as energy depletion, industrial overspecialization, deindustrialization, population aging and other crises

growth (Fig. 1b), has great influence on urban economic development. Urban economies, as a complex feedback system, usually demonstrate the characteristics of self-sustaining, self-organizing and self-renewal under the influence of disturbance. Resilience purports that the adaptive process of urban economies is a complex, non-linear, dynamic process with feedback, emergence and self-organization operating in conjunction (Hu, 2012). Based on the adaptive cycle model, the urban economic evolution process can be divided into four stages: exploitation, conservation, release and reorganization (Simmie and Martin, 2010) (Fig. 1c).

The link between industrial structure evolution and economic growth is not just close but reciprocal: industrial structure is not only a result of economic growth, but is also one of the fundamental factors that determines economic growth. Globally, developing a service-oriented industrial structure (especially high-end service industry) and high-end manufacturing are the two directions taken by leading metropoles in restructuring their industries (Li, 2009; Zhuo, 2013). As productivity growth of the tertiary industry is slower than the secondary industry, cities that adjust industry towards service must bear the challenge of slowing growth. At the same time, 'premature deindustrialization' may have long-lasting detrimental effects on economic growth by remove the main channel through which rapid growth occurs. Evolutionary resilience theory suggests that the key to achieving regional sustainable development is to create new growth paths (new pillar industries). For the old industrial cities with embedded systems of heavy industry, their starting point for industrial structure evolution is relatively high, and the old growth paths (old pillar industries) are and will remain the main sources of economic growth in the foreseeable future. Therefore, handling the relationship between old and new pillar industries is essential for a successful industrial structure evolution. In addition, since 1978, the industrialization and urbanization process in China has been basically promoted under a 'catch-up' mentality with a high degree of 'space-time compression' being a key feature. Cities are regarded as a meso-economic entity of national economy, and the economic growth rate is regarded as an important indicator. Long-term and high-speed growth is not only a feature of China's urban development, but also China's urban long-term pressure. During the transition from a macroeconomic recession to recovery, the relationship between resilience of urban industrial growth, service-oriented industrial structure, high-end oriented manufacturing, and industrial structure evolution has an important influence in promoting urban economy growth. Therefore, we focused on the relationship between the resilience of industrial growth and industrial structure evolution to analyze Shenyang's industrial structure evolution characteristics (Fig. 1).

3 Methods and Materials

3.1 Resilience measurement method

In this paper, we used Martin et al.'s economic cycle model (Martin et al., 2016) to measure the economic resilience and industrial growth resilience of Shenyang since the reform and opening up in 1978, so as to indicate urban economic growth capacity and industrial growth capacity, respectively. According to fluctuation trends in the Chinese GDP growth rate, and taking into account the 'four trillion' economic stimulus policies introduced in 2008, we used the 'valley to valley' economic cycle method (Deng and Qu, 2010). We further distinguished the recession phase and the recovery phase of the national economic cycle as follows: five recession phases take place from 1978 to 1981 (stage I, S1), from 1984 to 1990 (stage III, S2), 1992 to 1999 (stage V, S3), 2007 to 2011 (stage VII, S4) and 2011 to 2015 (stage VIII, S4); three recovery phases take place from 1981 to 1984 (stage II, R1), 1990 to 1992 (stage IV, R2) and 1999 to 2007 (stage VI, R3) (Fig. 1). Recession phases are indicated by '*Resis*' while recovery phase are marked by '*Recov*'. The specific formulas are as follows:

$$\left(\Delta G_c^{t+k}\right)^{expected} = g_N^{t+k} G_c^t \tag{1}$$

$$Resis_c = \frac{\left(\Delta G_c^{Recession}\right) - \left(\Delta G_c^{Recession}\right)^{expected}}{\left|\left(\Delta G_c^{Recession}\right)^{expected}\right|} \tag{2}$$

$$Recov_c = \frac{\left(\Delta G_c^{Recovery}\right) - \left(\Delta G_c^{Recovery}\right)^{expected}}{\left|\left(\Delta G_c^{Recovery}\right)^{expected}\right|} \tag{3}$$

In formula (1), the *expected* is that, other things being equal, city's output would contract (in recessions) and expand (in recoveries) at the same rate as that nationally.

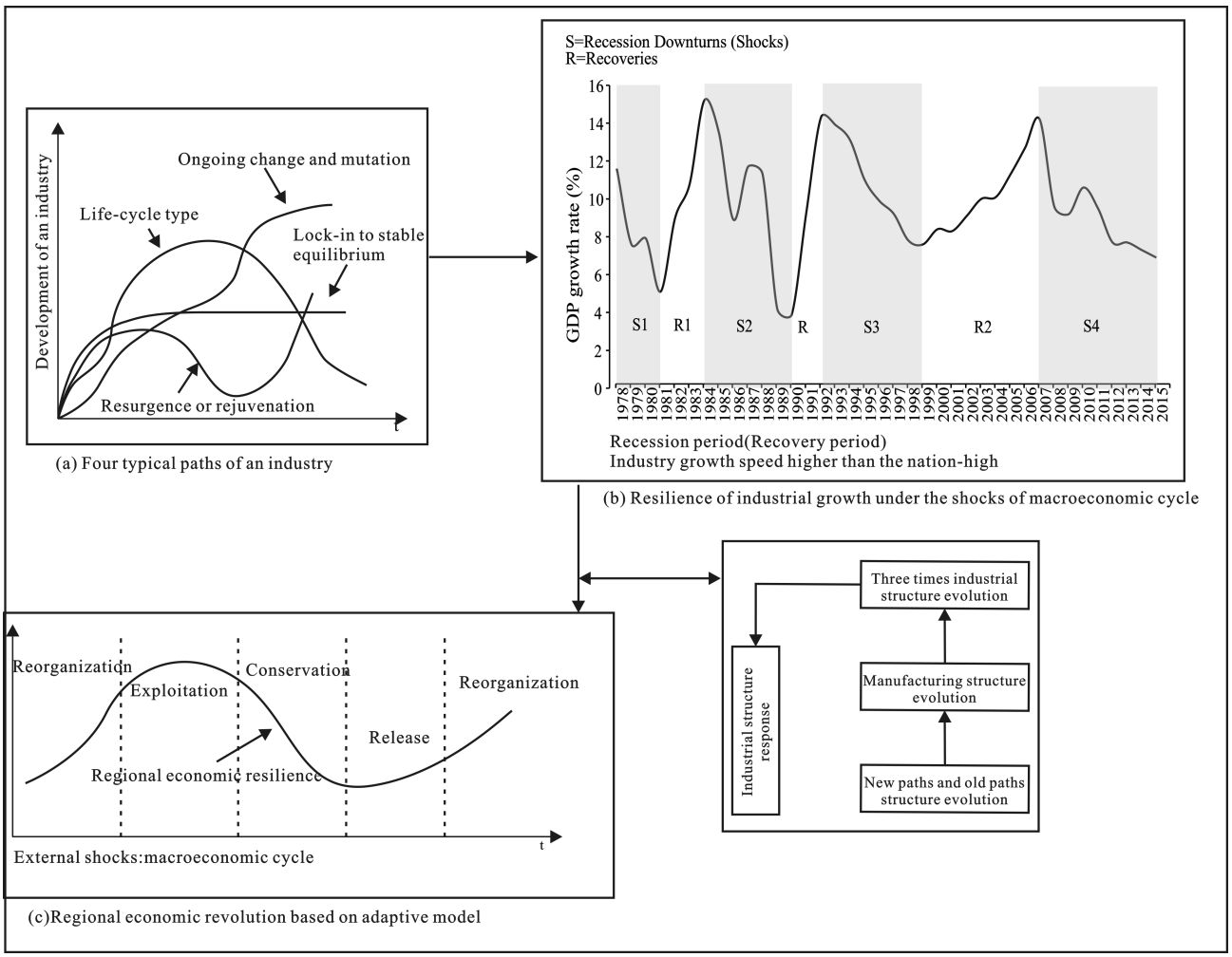

Fig. 1 Conceptual model of industrial structure evolution of old industrial cities based on evolutionary resilience theory. Source: 1a adapted from Martin (2010), Fig. 1b completed by author, Fig. 1c adapted from Martin and Sunley (2011)

Thus, the *expected* change in, say, output in a city during a recession or recovery, say of duration k periods, g_{N}^{t+k} represents the growth rate of the national economy or industry in a recession phase (recovery phase), and G_c^t represents the output of a city at starting time t, the base year, that is, the beginning of the recession or the recovery. A positive *Resis* means that the city is more capable of resisting contraction than the country as a whole (i.e., the city is less affected with a stronger capacity in economic or industrial growth), while a negative value indicates a lower resistance (i.e., the city is more affected with a weaker capacity in economic or industrial growth). For example, If *Resis* is 0.5, it indicates that the city's resistance capacity is 50% higher than the country's; if the value is –0.5, it indicates that the city's resistance capacity is only half of the country's. And so does *Recov.* We measured economic resilience by selecting GDP data, and resilience of industrial growth by selecting the second and tertiary industrial added value and the manufacturing industrial total output value, respectively. In this paper, we took OECD manufacturing taxonomy (Fu et al., 2014) for reference to divide manufacturing into three categories, namely, high-end technology industry, mid-end technology industry and low-end technology industry①. In order to better reflect the real-time situation of economic and industrial

①High-end technology industries include general equipment, special equipment, transportation, electric machinery and equipment, communications electronics, instrumentation, office-used machinery, chemistry, pharmaceutical industry and other industries; mid-end technology industries include petroleum processing, coking and nuclear fuel processing industry, rubber, plastic, non-metallic mineral, ferrous metal smelting, nonferrous metal smelting, metal products, *etc*.; low-end technology industries include food processing, beverage, tobacco, textile, clothing, leather, wood, furniture, papermaking, print, stationery and sporting goods and other manufacturing industries

growth, we used the data from the current year.

3.2 Data source

Statistical data were primarily obtained from *China Statistical Yearbook 1986–2016* (National Bureau of Statistics of the People's Republic of China, 1986–2016), *China Statistical Yearbook on Science and Technology 2005–2016* (Society, Science and Technology and Culture Industry Statistics Department, National Bureau of Statistics, Department of Innovation and Development, Ministry of Science and Technology, 2005–2016), *China Industrial Statistics Yearbook 2001–2016* (National Bureau of Statistics, Department of Industrial Statistics, 2001–2016), *Shenyang Statistical Yearbook 1995–2016* (Shenyang Statistics Bureau and Shenyang survey team of the National Bureau of Statistics, 1995–2016), and *Shenyang Economic Statistical Yearbook 1985–1991*(Shenyang Economic Statistical Yearbook Editorial Board, 1985–1991). Part of the data obtained from the economic census yearbook, the urban statistical annual report and the city yearbook from relevant years were used as supplement. The average value from the year before and the year after was used to replace the missing year's data.

4 Results

4.1 Resilience of industrial growth characteristics and structural response

The characteristics of Shenyang's economic resilience are highly consistent with the adaptive cycle theory (Fig. 2). According to the four-stage periodic model of regional development of adaptive cycle theory, Shenyang economic development can be divided into the following stages: from 1981 to 1992, Shenyang experienced conservation stage and was in the release stage, and in 1989, one-third of the industrial enterprises in Shenyang suffered losses. The number of unemployment reached 64 000; from 1992 to 1999, Shenyang was in the stage of the transition period from release to reorganization, and in 1997, 38.8% of the state-owned large and medium-sized enterprises suffered losses. By 1999, 60% of the municipal state-owned large and medium-sized enterprises initially set up a modern enterprise system, and their business losses dropped to 30%; from 1999 to 2007, Shenyang experienced reorganization and was in the development stage; in 2002, Shenyang's Tiexi District and its Economic and Technological Development District jointly handled official affairs, especially in 2003, the process of rejuvenation was started with 18 state-owned large and medium-sized enterprises being restructured into listed companies. In 2007, Shenyang Yuanda, Shenyang Machine Tool, GM (Shenyang) Beisheng, Brilliance BMW and North Heavy Industries became the new ten billion groups; and from 2007 to 2015, it was in the transition period from conservation to release, during which from 2007 to 2010, the number of industrial enterprises above state designated size increased by 870, while the number of industrial enterprises above state designated size from 2010 to 2015 decreased from 5252 to 3284 with its deficit increased from 6.9% to 10.7%.

4.1.1 Resilience change and structural response of industrial growth

Fig. 2 shows the growth capacity of Shenyang reflected by the resilience of growth of the secondary and tertiary industry since 1978. Before 1990, the tertiary industrial growth capacity level of Shenyang was significantly higher than the average level of the country. Since then,

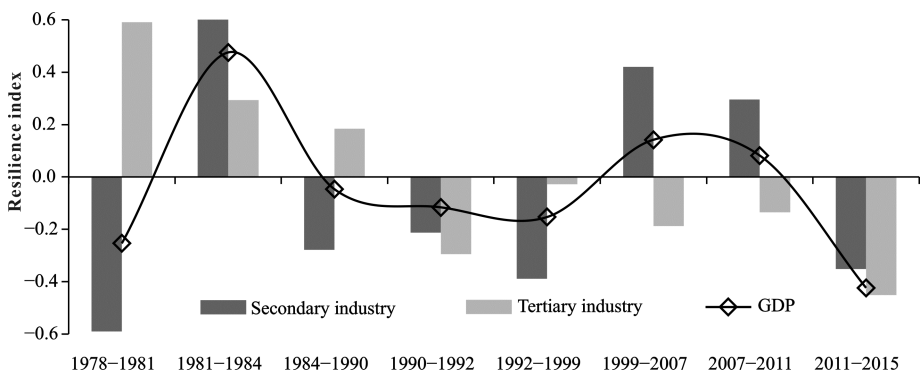

Fig. 2 Economic resilience of the secondary and tertiary industry in Shenyang

the level has been lower than the national average. The growth capacity of the secondary industry of Shenyang was still lower than the national average from 1984 to 1999. The growth capacity was higher than the national average during the period of 1999 to 2011, however, when the Chinese macro economy entered a 'new normal', its growth capacity decreased obviously, Shenyang was again below the average, showing a cyclical characteristic of fluctuations. Overall, the growth capacity of the secondary industry in Shenyang experienced fluctuating expansion and contraction. In its recovery phase, it showed a much stronger expansion force, and in the recession phase, it showed a much stronger contraction force.

There are significant differences of the changes of resilience between the second and the tertiary industry in Shenyang. The growth capacity between its second and tertiary industry did not develop in unison. The change of the proportion between the tertiary industry and the secondary industry (Fig. 3) reflects that the industrial structure in Shenyang had a greater volatility than China as a whole. Specifically, the industrial structure evolution in Shenyang can be divided into three phases. From 1978 to 1984, the secondary industry was the leading sector, and the tertiary industry grew slowly. From 1984 to 1999, the tertiary sector became the leading sector. Since 1999 the proportion of the tertiary industry declined and the structure was characterized by a balanced approach between the secondary and tertiary industry.

Combined with Fig. 2, we can see that from 1984 to 1999 and from 2011 to 2015, the substantial increase in the proportion of Shenyang's tertiary industry was mainly due to a slowdown in secondary industry growth in the context of a decline in urban economic growth capacity. During the period of 1999 to 2007 and 2007 to 2011, the economic growth capacity of Shenyang was higher than that of the nation, and the proportion of tertiary industry declined rapidly. This indicates that the service-oriented economic structure of Shenyang was primarily due to the slowdown in industrialization, rather than active industrial restructuring towards tertiary industry.

4.1.2 Resilience change and structural response to manufacturing growth

Fig. 4 shows the changes in resilience in the growth of the high-end, the mid-end and the low-end technology industries, which can be divided into three stages. From 1985 to 1999, the growth capacity of the three types of industry is roughly equal to or lower than that of the whole country. From 1999 to 2011, the growth capacity of the three types of industry is higher than that of the national average, with the growth capacity of low-end industries much higher than that of high-end industries. From 2011 to 2015, the growth capacity of the three types of industry again fell below the national average, and the growth capacity of both the mid-end and the low-end industries contracted significantly. By comparing the performance of the three types of technology industries in a recession phase and recovery phase, it can be found that the anti-contraction capacity of the high-end industries in Shenyang is stronger than that of the mid-end and low-end industries.

Changes in proportion of the high-end technology industries in the manufacturing sector (Fig. 5) indicate that the restructuring of the manufacturing sector towards high-end technologies has a greater volatility in Shenyang than in China as a whole. From 1985 to 1999, the shift towards a higher proportion of high-end manufacturing in Shenyang was the same as that of the whole country. However, when China began its re-industrialization of

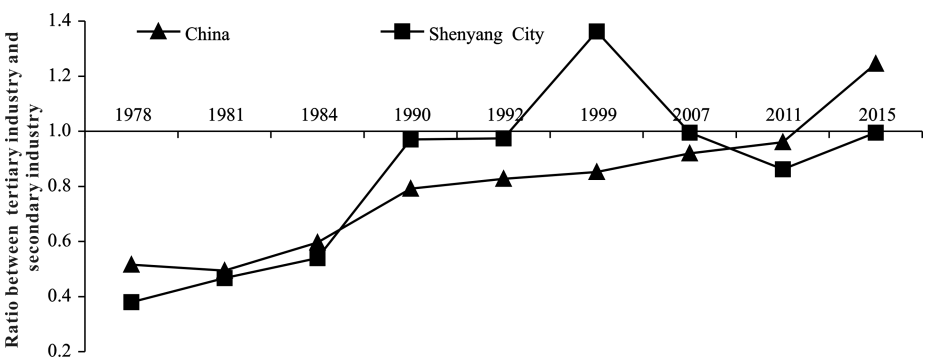

Fig. 3 Change of ratio between the tertiary industry and the secondary industry in Shenyang and China

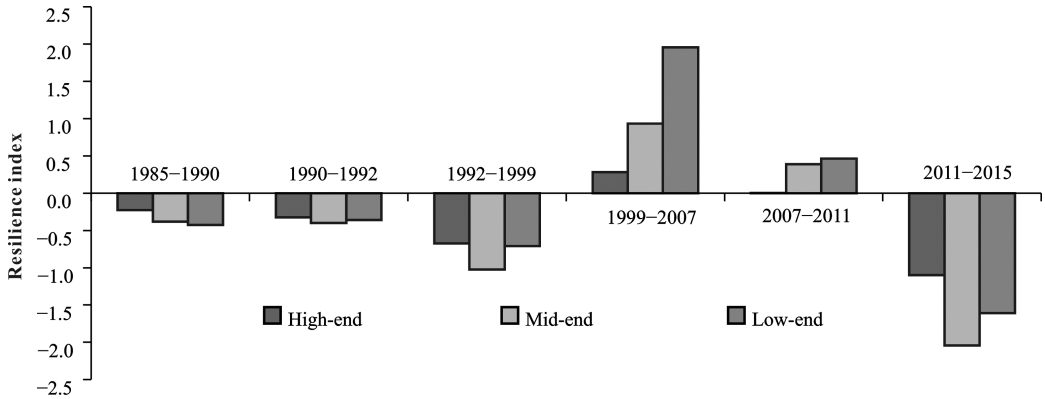

Fig. 4 Resilience changes of the high-end, the mid-end and the low-end technology industries in Shenyang

heavy industry (the second heavy industrialization strategy) from 1999, the high-end orientation of manufacturing in Shenyang began to weaken, whereas it strengthened nationally. In Fig. 4, we see that the high-end orientation of manufacturing in Shenyang from 1985 to 1999 was carried out under the context of a lower than average industrial growth capacity. From 1999 to 2011, in contrast, the process was carried out in the context of higher than average industrial growth capacity. From 2011 to 2015, the shift towards high-end manufacturing increased pace again, which was mainly caused by a significant contraction in the growth capacity of the mid-end and low-end industries.

4.2 Structure evolution and development characteristics of the new path and old path in Shenyang

4.2.1 Definition and structural evolution of the new path and old path

In the long run, the formation of new industries not only offsets the negative impacts brought about by the de cline of old industries, but also becomes an important driver of the growth of the city by creating new paths (Hu et al., 2011). The industrial structure evolution emphasizes the replacement of pillar industries. The emerging pillar industries in cities are generally large in scale and comparatively advantageous, and will not be completely withdrawn in the short term, which will have a great impact on the urban industrial structure. Emerging industries, however, generally smaller in their initial stage, may decline and completely withdraw from the industry in a short term with a relatively small impact on the urban structure. In addition, in order to observe the continuity of structural change between old paths and new paths for a long time, in this paper, we use pillar industry to indicate new paths and old paths of the city. Specific principles are as follows: first, subjected to the limitations of statistical data and industry classification changes, we only considered the changes in pillar indus-

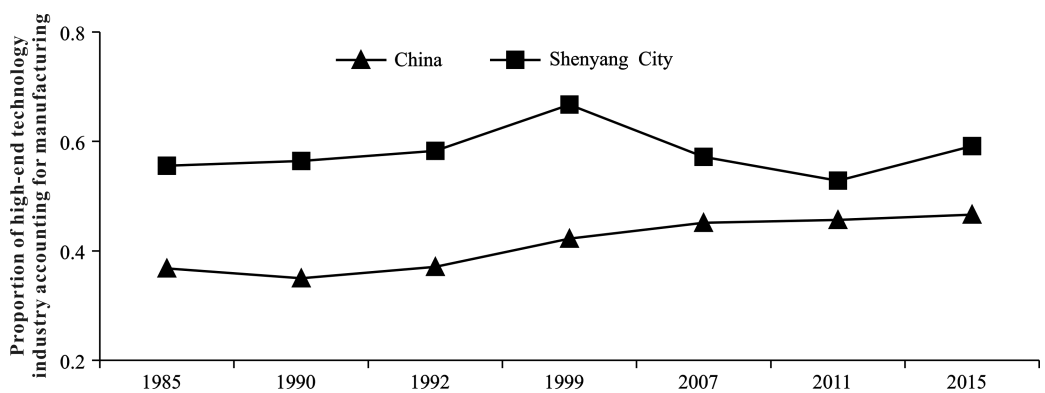

Fig. 5 Change of proportion of high-end technology industry accounting for manufacturing in Shenyang and China

tries after 1984 and merged industries which involve industry classification changes[①]. Double-digit industries were selected from the manufacturing sector with their total output value surpassing 7% of the total output value of the manufacturing sector, and such industries were defined as pillar industries (Zheng, 1995). Based on the distinction between recession and recovery phases, we defined the old pillar industries as industries that appear in at least one year in all phases, and the portfolio of all old pillar industries is defined as the old path. We defined new pillar industries as the newly emerged industries that were not present from 1985 to 1990, and the industry portfolio is defined as the new path. The evolution process of pillar industries and the definitions of the old path and new path in Shenyang are shown in Table 1.

From 1985 to 2015, all old pillar industries in Shenyang belonged to the high-end technology category, whereas the new pillar industries belonged to three very different types of industries. The metallurgic industry and the textile industry in the mid-end and the low-end technology sectors respectively had disappeared. From 1992 to 1999, the evolution of Shenyang's pillar industries was the strongest. Taking the change of the proportion of the new path in the old path and new path as the representative of the evolution process of the new path and old path, the evolution process of the new path and old path in Shenyang City has great volatility and obvious stage characteristics. From 1985 to 1992, the structural state between the old path and the new path was stable at around 0.18; from 1992 to 2015, the structural evolution of the new path and the old path had relatively large fluctuation and the evolution process dropped back. The proportion of new path was first increased from 0.17 in 1992 to 0.35 in 2011, and then dropped to 0.29 in 2015.

4.2.2 The new path and old path development characteristics in Shenyang

The Northeast's old industrial saw the most thorough execution of the planned economic system over the longest period. It is the place which entered the planned economy the earliest and exited the planned economy the latest, experiencing the deepest impact from the planned economy (Chen et al., 2016). Institutional contradictions and lack of innovation have long been the problems in Shenyang that need to be solved. Therefore, we used three indicators of development: innovation (i_1 the proportion of new products output value accounting for that of the country), marketization (i_2 the proportion of non-state-owed rate, namely, non-state holdings accounting for that of the country), and economic extroversion (i_3 export delivery value accounting for that of the country). By constructing the development level index: $Index=i/I$, i is i_1, i_2, i_3 respectively, I is the proportion of the overall output value of the new and old pillar industries accounting for that of the corresponding industry of the country. We analyzed the changing characteristics of the new path's and old path's development

Table 1 Evolution process of pillar industries and the new path and old path industry composition in Shenyang

Pillar industry	Recession 1985–1990	Recovery 1990–1992	Recession 1992–1999	Recovery 1999–2007	Recession 2007–2015
All pillar industries during the period	Non-ferrous metal smelting, machinery industry, transportation, electric machinery and equipment	Non-ferrous metal smelting, machinery industry, transportation, electric machinery and equipment	Food processing and manufacturing, nonferrous metal smelting, machinery industry, transportation, electric machinery and equipment, communication electronics	Food processing and manufacturing, machinery industry, transportation, electric machinery and equipment, communication electronics	Food processing and manufacturing, non-metallic minerals, machinery industry, transportation, electric machinery and equipment
Old path	Machinery industry, transportation, electrical machinery and equipment				
New path	Food processing and manufacturing, non-metallic minerals, communications electronics				

①Merging between some double-digit manufacturing industries: agricultural and sideline food processing industry (feed industry) and the food manufacturing industry are merged into food processing and manufacturing industry; petroleum processing and coking, gas and coal products industry are merged into oil processing, coking and nuclear fuel processing industry; general equipment manufacturing, special equipment manufacturing and arms and ammunition manufacturing industry are merged into machinery industry; automobile manufacturing and railway, ship, aerospace and other transportation equipment manufacturing industry are merged into transportation equipment manufacturing industry

levels in Shenyang since 2001 (Figs. 6–7). The index greater than 1 indicates that the level of development is high, and vice versa. On a whole, from 2001 to 2015, the development level of the new path and the old path was low and experienced significant decline in innovation and economic extroversion. The development level of marketization was however improved. The old path was still lower than the national level, the new path was roughly equal to the national level, but the process was slow after 2007. Specifically, the degree of change in the innovation development index of the old path was the largest, dropping from 1.64 in 2005 to 0.58 in 2015; the degree of change in economic extroversion of the new path was the largest, dropping from 1.31 in 2003 to 0.18 in 2015. In addition, the innovation development of the new path was the lowest, far below the national level.

Based on the results of the evaluation of the development level of the old path and the new path in Shenyang from 2001 to 2015, we used the proportion of output value of new products of that of the country to measure the change in innovation output growth capacity of the new path and the old path (Y). The predictors should be considered according to three aspects: capital (C), labor-human capital (L) and technology (A). We used five variables as predictors: the proportion of R&D internal expenditure of that of the country (C), the proportion of people in scientific and technological projects of that of the country (L), the proportion of scientific and technological projects of that of the country (A_1), the proportion of enterprise-owned science and technology institutions of that of the country (A_2), and the proportion of invention patents of that of the country (A_3). To overcome the influence of multiple collinearity caused by the correlation of independent variables, the ridge regression method (Tong, 2005) was used to analyze the influencing factors of the innovation growth ability of the new path and the old path in Shenyang from 2007 to 2015. K, regression model test and model ridge regression coefficient are shown in Table 2.

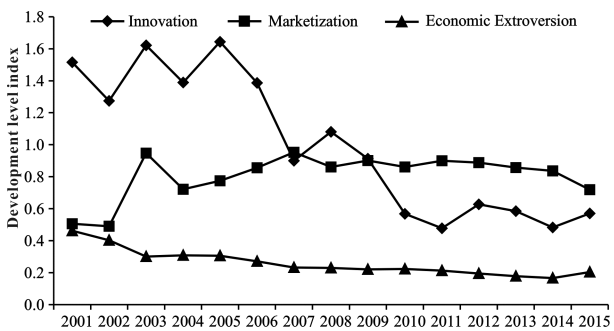

Fig. 6 Shenyang old path development level index

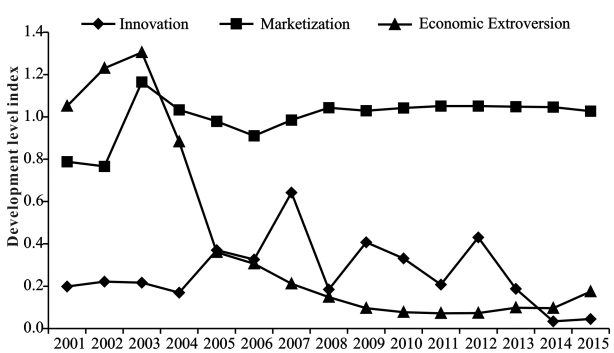

Fig. 7 Shenyang new path development level index

The innovation growth ability of the transportation industry and communications electronics industry is most affected by the capacity for human capital growth. The innovation growth ability of the electric industry is most affected by the growth ability of science and technology institutions. The innovation growth ability of the machinery industry is most affected by capital growth ability. In general, the innovation growth ability of the old path in Shenyang is mainly affected by the growth ability of human capital and that of science and technology institutions, while the influence of capital, number of science and technology projects and the growth ability of invention patents on industrial innovation growth ability is not that significant. This finding suggests that there exist problems related to brain drain and the lack of application of scientific knowledge in the northeastern region. In addition, the slow growth in the number of enterprise-owed science and technology institutions has affected the increase in the amount of sustained and stable R&D activities, thus affecting scientific and technological innovation output. However, there is no significant relationship between the innovative growth ability of the new path, the agricultural and sideline food processing, and non-metallic mineral products and the growing ability of the explanatory variables listed in this paper. It is noteworthy that that in 2015, the index of innovation and development in three major industries, namely, agricultural and sideline food processing, non-metallic mineral products, and communications electronics, were 0.19, 0.03 and 0.06 respectively, far less than 1. The above three industries, as the new path of economic growth in Shenyang, and their low level of innovation indicate that Shenyang industries lack

Table 2 Analysis results using ridge regression

Standardized regression coefficient (*Beta*)	Old path	Machinery	Transportation	Electrics	Electronics
C	–0.136	0.305*	–0.338*		0.138
L	0.442**	0.196*	0.482**	0.065	0.312**
A_1				0.353**	0.225*
A_2	0.441**	0.224*		0.378**	0.306*
A_3			0.387*		
Constant	0.00	0.00**	0.00	0.00	0.00
Adj R^2	0.681	0.499	0.675	0.678	0.735
Sig. *F*	0.033	0.097	0.034	0.034	0.047
K	0.2	0.5	0.3	0.4	0.6

Notes: ** and * represent a significant result under 5% and 10% confidence level respectively. *C* is the proportion of R&D internal expenditure of that of the country, *L* is the proportion of people in scientific and technological projects of that of the country, A_1 is the proportion of scientific and technological projects of that of the country, A_2 is the proportion of enterprise-owned science and technology institutions of that of the country, and A_3 the proportion of invention patents of that of the country

innovation. We will analyze the issue of weak innovation of Shenyang in follow-up studies.

5 Discussion and Conclusions

Based on the theory of resilience and the characteristics of regional development, we constructed an analytical framework of industrial structure evolution. On this basis, we conducted an empirical study on the evolution characteristics of the industrial structure of Shenyang since 1978. The conclusions are as follows. First, the industrial growth capacity of Shenyang has shown fluctuation and changing characteristics between contraction and expansion with a greater degree of fluctuation evident in the expansionary force and contractionary force of the growth capacity of the secondary industry. The transformation direction of industrial structure has experienced greater fluctuation. The rapid upgrading of the economic structure of the service sector is not a reflection of active industrial restructuring, but of the slow progress of industrialization. Especially since the implementation of the revitalization strategy, the degree of coordination between the secondary industry and the tertiary industry has been low. Second, since 1999, China has begun to re-industrialize its heavy industries. However, high-end manufacturing in Shenyang showed an opposite trend with its development being slow and unstable. Especially since the implementation of the revitalization strategy, the mid-end and low-end industries in Shenyang have showed stronger expansion and contraction. Third, the old pillar industries of Shenyang are in the high-end technology category, whereas the new pillar industries are distributed in the high-end, the mid-end and the low-end technology industries. As such, the industrial structure evolution of Shenyang has been oriented towards low-end manufacturing. Fourth, since the beginning of the 21st century, the development level of the new path and the old path in Shenyang has been low with great fluctuation in levels of economic extroversion and innovation. After 2007, the ability of innovation output decreased significantly, mainly affected by human capital and the number of science and technology institutions, and to a lesser extent by capital. In addition, the old path, composed of mechanical industry, transportation industry, electrical industry, *etc*., were slow to marketize and even showed a decline in this process. The new path, composed of agricultural and sideline food processing, non-metallic minerals, communications, *etc*., were faster to marketize, but the level of innovation and economic extroversion was far below the national level.

At present, the study of regional resilience is still in its infancy and lacks a mature theoretical framework. This paper contributes to the literature by constructing a conceptual model of industrial structure evolution from the perspective of resilience, but there are some limits. First, as the industrial growth capacity represented by the economic resilience of the industry was compared with the national average. The cities which are in a period of rapid industrialization transforming from the middle stage of industrialization to the mid-late stage of industrialization can be measured accurately in terms of industrial economic resilience, but for cities such as Beijing, Shanghai, Guangzhou, etc., which have taken

the service economy as their leading sector, the applicability of the model remains to be tested. Second, at present, we still lack a theoretical framework to fully understand the evolution of industry from the perspective of evolutionary resilience because there are limits in explaining the formation of new industries in cities (Hassink, 2010). This paper mainly analyzed the evolution characteristics of the old and new path in Shenyang and has limited insight on the path formation mechanisms. For this reason, it is necessary for us to develop a new resilience theory, strengthen empirical understanding of this concept through urban and regional studies, and clarify its implications to provide guidance for urban and regional development.

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