Research on Industrial Innovation Efficiency and the Influencing Factors of the Old Industrial Base Based on the Lock-In Effect, a Case Study of Jilin Province, China

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Abstract: In the context of the increasingly intensified innovation competition, improving industrial innovation efficiency is the key to achieving the sustainable development of the old industrial base. This paper adopts the thinking of regional research to study the laws of industrial innovation in the old industrial base and takes the lock-in effect as the connection point between the industrial evolution history and industrial innovation efficiency. Based on the perspective of the lock-in effect, the three-stage industrial innovation model, the lock-in effect identification method, and the extended Porter model are creatively constructed. This paper chooses Jilin Province in Northeast China as a case, dissects the evolution history of industrial innovation in detail, and uses super-efficiency DEA, the Granger test, geographical detectors, and the panel regression method for quantitative analysis. The results show the following: (1) The lock-in effect faced by the industrial innovation of the old industrial base is significant, which has an impact on industrial innovation through industrial structure, enterprise composition, management system, and degree of marketization. (2) The lock-in effect causes the old industrial base to fall into an unhealthy circle in which it is difficult for industrial enterprises to obtain sufficient benefits through industrial innovation and the ability of industrial enterprises to absorb regional innovation resources is weakened. (3) The impact mechanism of industrial innovation in the old industrial base is very complex and the lock-in effect factors are not all negative. The improvement of industrial innovation in the old industrial base needs to increase the role of market forces, reform large traditional enterprises, and increase foreign economic ties. However, it also needs policy support, and it should avoid overly radical industrial transformation and enterprise strategies.

Keywords: old industrial base; industrial innovation efficiency; lock-in effect; three-stage innovation model; extended Porter model

1. Introduction

In the research on innovation efficiency and its influencing factors, the research scales and indicators selected are diverse. In the research on the measurement of innovation efficiency, the scales include international [1,2], country [3–5], region [6,7], a specific industry [8–11] and enterprise [12–14], and there are few studies on the intercity scale. The use of indicators above the provincial scale is too macro to reflect the special influencing factors of the intercity scale, and some micro studies cannot reflect the overall appearance of industrial evolution and development. Regarding the use of innovation efficiency influencing factors, the current research has some common points, such as government influence [15,16], public R&D investment [17], and financial development [18]. However, when studying different objects, different influencing factors are often selected as indicators. For example, in the power industry, innovation research market segmentation was chosen as the influencing factor [19]. In the semiconductor industry innovation research, the level of venture capital and the integrity of the industrial chain were chosen as the influencing factors [8]. For
innovative research with a large spatial scale, the idea of constructing an indicator system usually tends to spatial econometrics. For innovation research with a small spatial scale, the idea of constructing an indicator system is usually inclined to business and management. There is relatively little innovative research based on the mesoscale regional perspective that can dissect regional evolution and regional characteristics in detail. However, with the emergence of industrial innovation centers with obvious regional characteristics such as Silicon Valley and Shenzhen, innovation has already become a typical regional problem.

Generally speaking, most of the relevant studies on innovation efficiency and influencing factors only measure the efficiency of R&D of innovative achievements in a certain period of time and demonstrate the significance of each influencing factor. Few studies can combine the current innovation performance with the past regional evolution and make an in-depth analysis of this relationship. Relevant studies often analyze each influencing factor as an isolated dimension, which is difficult to simulate the highly complex regional innovation mechanism [20–22]. The reason for this dilemma is that the research of innovation efficiency faces the conflict between space breadth and time breadth. If we study innovation efficiency on a large spatial scale, it is difficult to clearly analyze the causal relationship between the evolution history and the impact mechanism of innovation. Because the evolution paths of different small areas within the scope of the study are highly heterogeneous, and most of them have no obvious characteristics. If a study wants to clarify the relationship between current innovation and past evolution, it should choose regions with strong typicality in historical evolution [23,24]. The evolution history of such regions often has a relatively clear logic line with a long duration, which is convenient for in-depth study of the impact mechanism of innovation. Such a research idea is just in line with the regional research that human geography is good at [25,26], and the old industrial base is a very suitable research object.

The old industrial base has the characteristics of a simple evolution context and complex evolution mechanism (the industries referred to in this paper include the extractive industry, manufacturing industry, electricity, heat, gas and water production, and the supply industry). The evolution history of the old industrial base is the continuation of the industries originally laid out, and a complex evolution mechanism involving society, economy and culture is formed around a single logical line of historical evolution [27,28]. Inadequate innovation, especially the low innovation efficiency, is a typical problem faced by these old industrial bases with a strong industrial foundation due to their long history of industrial evolution. The old industrial bases are in urgent need of getting rid of the adverse effects of industrial evolution history and improving innovation efficiency to achieve sustainable development. For example, many old industrial bases in China once rose in a short time, but soon after that, under the pressure of global competition, the problem of unsustainable development emerged. The innovative research based on the regional research perspective of geography can better analyze the realistic characteristics of the region formed due to the special evolution history and put forward more realistic guiding opinions. For the old industrial base, the lock-in effect can be a key hub to link the regional long-term industrial evolution history with the current complex industrial innovation impact mechanism. The industrial evolution in the past played a role in the industrial innovation of the old industrial base through the lock-in effect.

The lock-in effect originated from the path dependence theory. It was first introduced in the field of social sciences by David, an American economic historian [29]. Arthur systematically developed this theory [30]. North expanded to the institutional path dependence theory [31]. With the deepening of the understanding of this problem by scholars of evolutionary economic geography, the discussion of path dependence and path creation has also become a hot topic in recent years. Innovation, institutions, and the role of leaders have become important factors used to eliminate the lock-in effect [32]. Due to the special evolution history and the concentration of capital-intensive industries [33], the industrial development of the old industrial base is likely to fall into the lock-in effect. Historically, because of the inherent resource endowment, geopolitical influence and
policy planning [34], the old industrial base is very likely to form an economic structure in which heavy industry accounts for a large proportion and large enterprises occupy a dominant position. Because of the high specificity of assets, the high cost of upgrading equipment, the strengthening of professional barriers and the improvement of economies of scale under the heavy industry system [35], as well as the increasing returns brought by upstream and downstream networks and supporting groups [36], the old industrial base was likely to fall into path-dependent growth. The dependence on existing technologies caused by technology relevance [37] and the path dependence from technology dependence to institutions [31] make it difficult for the old industrial base to overcome the lock-in effect. The means of production, talent, technology and information of the old industrial base are locked in the original cluster [38]. The knowledge heterogeneity of the old industrial base is weakening. The organizational structure and network of the old industrial base are becoming rigid. The enterprise derivation of the old industrial base falls into path dependence. The old industrial base evolves into a rigid specialized single structure area. The lock-in effect has become the core constraint affecting innovation transformation.

From the perspective of the lock-in effect, this paper selects cities (prefectures) in Jilin Province as the cases. The reason for choosing Jilin Province as the case is that Jilin Province is located at the core of Northeast China, the most typical old industrial region in China. Compared with the neighboring provinces, Jilin Province has been less affected by resource curse factors and international trade factors for a long time and can more clearly show the evolution of the old industrial base. Moreover, the leading industries of Jilin Province are the automobile industry and the chemical industry, which have strong reference significance for old industrial bases around the world. Around the whole process from the comparative advantage of industrial innovation resources to the competitive advantage of industrial innovation achievements, this paper uses super-efficiency DEA to measure the efficiency of the following three stages: the transformation of innovation resources (TIR), research and development of innovative achievements (RIA), and innovation benefits-driven (IBD). Then, the Granger method and geographical detectors are used to verify the existence of the lock-in effect. Finally, this paper selects the influencing factors that can reflect the regional characteristics of the old industrial base and uses panel regression analysis to demonstrate these influencing factors, and then puts forward suggestions.

The main academic contribution of this paper is to combine regional evolution history with industrial innovation efficiency (IIE) and apply the regional research ideas of geography to innovation research. The main practical contribution of this paper is to dissect an old industrial area that has been restricted by insufficient industrial innovation for a long time and put forward concrete suggestions with data support for the sustainable development of the old industrial base from the perspective of innovation. In order to achieve the above goals, three major innovations have been made in this paper: (1) In addition to the technological innovation of industrial enterprises, the utilization of regional innovation resources and the profitability of innovation achievements are also included in the research of industrial innovation, forming a three-stage industrial innovation analysis model. This analysis model is used to solve the problem: What are the time and space characteristics of the IIE of the old industrial base? (2) The lock-in effect is regarded as the connection hub between the regional evolution history and the current IIE, and a set of ideas and methods to identify the lock-in effect are constructed. This set of methods is used to solve the problem: Is the lock-in effect of industrial innovation in the old industrial base significant? In particular, can it be identified by statistics? (3) From the perspective of innovative geography, this paper expands the classical Porter model and constructs an index system containing multiple scale influencing factors. This indicator system is used to solve the problem: What factors affect the industrial innovation of the old industrial base? In particular, what is the mechanism of the impact of the lock-in effect on industrial innovation?
2. Theoretical Analysis Framework

2.1. Evolution of Industrial Innovation in Jilin Province

During the period of the planned economy, China established many industrial bases, which are different from the industrial bases that emerged after the reform and the opening up in terms of development path and characteristics. These old industrial bases have historically relied on mandatory operations in product production and resource allocation and are relatively slow to innovate and transform under the market competition mechanism [39]. Northeast China is a typical area with a concentrated and continuous distribution of old industrial bases, which was once one of the most important industrial areas in China. However, these old industrial bases, located far from the core market, did not perform well in adapting to subsequent changes [40]. In recent years, although the industrial innovation capacity of the old industrial bases in Northeast China is higher than that in the past, the competitiveness of industrial innovation is not as good as that of the emerging industrial zones along the coast of China [41]. The industrial sustainable development ability is in crisis and the lack of innovation-driven is the core constraint hindering the industrial transformation [42].

Jilin Province is located in the middle of Northeast China and the geographical center of Northeast Asia. It governs one subprovincial city, seven prefecture-level cities, and one autonomous prefecture, refer to Figure 1. The provincial capital of Jilin Province is Changchun. Jilin Province is an important industrial base in China and includes automobile and rail transit manufacturing, petrochemical industry, pharmaceutical industry, optical machinery industry and agricultural products processing industry. Jilin Province is a typical area with a continuous distribution of old industrial bases. Changchun, Jilin, Laioyuan, Tonghua and Baishan are the layout points of 156 key projects assisted by the Soviet Union during the First Five-Year Plan. During the Second Five-Year Plan, the Fuyu oil field was discovered in Songyuan City and Fuyu Petrochemical Plant was established. In addition, the agricultural machinery and heat exchanger industry in Siping and the textile industry in Baicheng were also important industries laid out during the planned economy period.

![Figure 1. Study area (Date from: https://www.resdc.cn/Default.aspx, accessed on 30 August 2022).](https://www.resdc.cn/Default.aspx)

The industrial innovation in the old industrial bases of Jilin Province has mainly experienced the following three stages of evolution: the stage in which the planned economy occupied a dominant position, the stage in which the influence of market and foreign capital was rising, and the stage in which multiple factors exerted influence together. Be-
Before China’s reform and opening up, the industrial innovation in the old industrial base of Jilin Province was in the stage in which the planned economy occupied a dominant position. During this period, many large state-owned enterprises were established. The innovation activities of industrial enterprises mainly occurred in state-owned enterprises. The typical representatives included the First Automobile Factory of China, “three major chemical plants” in Jilin (a fertilizer plant, dye plant, and calcium carbide plant), Fuyu Petrochemical plant in Jilin province, etc. Jilin Province, with a weak industrial foundation, greatly enhanced its industrial innovation ability, but the lock-in effect was also gradually produced. After China’s reform and opening up and before the global financial crisis, the impact of the market and foreign capital was on the rise. At this time, the market economy developed rapidly, and a large number of foreign capital entered China. Traditional industrial enterprises in Jilin Province began to reform, and many enterprises chose to cooperate with foreign investors in R&D. For example, First Automobile Works cooperated with Volkswagen. At the same time, enterprises of various ownership settled in succession, and many of them had industrial innovation activities, such as GenSci Pharmaceutical and Xiuzheng Pharmaceutical, which improved the flexibility of industrial innovation of the old industrial bases. During this period, market competition forced industrial enterprises to accelerate innovation, but also led to excessive dependence on foreign technology, and the lock-in effect continued to deepen. After the global financial crisis, the industrial innovation in the old industrial base of Jilin Province is in the stage in which multiple factors exerted influence together. Policy, diplomacy, market, and foreign capital still play an important role, and the influence is relatively stable. At the same time, the influence of internal factors increases, including innovation environment, enterprise strategy, and so on. Industrial enterprises pay more attention to improving the ability of independent innovation and building independent brands, and the combination of industry, universities, and research is closer. The traditional imitation innovation comes to an end and the restrictive effect of the lock-in effect on industrial innovation is more prominent. This is because independent innovation is more sensitive to the innovation environment. In other words, industrial innovation in Jilin Province experienced an evolutionary process from nothing to creation and from imitation innovation to independent innovation. However, with the continuous improvement of the level of industrial innovation, it increasingly became restricted by the lock-in effect. From the perspective of innovation subjects, large state-owned industrial enterprises have always been the main innovation subjects among industrial enterprises in Jilin Province.

From the perspective of the lock-in effect, because the industrial innovation and development of the old industrial bases in Jilin Province were in the stage in which the planned economy occupied a dominant position for a long time, the industrial structure was relatively simple, the regional innovation resources mainly served the traditional large enterprises, the degree of administrative intervention in industrial development was relatively deep, and the enterprise innovation strategy did not take market factors into account enough. In the stage in which the influence of market and foreign capital was rising, the administrative intervention was significantly reduced. However, due to the weak ability of industrial innovation, the development of industrial enterprises was still inseparable from the help of policies. In addition, because the location was far away from the market and the technology was relatively backward, it was difficult for small and medium-sized enterprises to cope with market competition, and these enterprises were not the priority choice for foreign capital to seek cooperation. Therefore, the dominant position of traditional large enterprises was not shaken. These large enterprises were able to siphon a large number of regional innovation resources. Most industrial clusters took these large enterprises as the core, and emerging industries faced a crowding-out effect. In the stage in which multiple factors exerted influence together, the influence weight of small and medium-sized enterprises and emerging industries in industrial innovation is on the rise. The enterprise composition structure and industrial composition structure of the old industrial base gradually diversified. However, due to path-dependent growth, the rise
of small and medium-sized enterprises and emerging industries has not broken the past situation. Emerging industries are small in scale and face a crowding-out effect, the degree of administrative intervention is deep and the management system is rigid, large enterprises occupy a dominant position and small enterprises have insufficient development levels, and some industrial enterprises' innovation strategies deviate from the realistic needs, which are still the four most important dimensions of the lock-in effect. These four dimensions exist in many old industrial bases in China and even in the world, which reflects the long-term evolution of the old industrial bases and are the main channels for the impact of the lock-in effect on industrial innovation. The incongruity between innovation and market directly affects the smoothness of the whole process of industrial innovation from regional innovation resources to the regional innovation economy. This dimension will be reflected in the efficiency measurement results of the first and third stages of industrial innovation. The other three dimensions jointly affect the innovation environment of technological innovation, which will be reflected in the demonstration of the influencing factors of IIE in the second stage.

By combing the industrial evolution history of the case area, it can be found that the lock-in effect can always affect industrial innovation through these four dimensions, as the internal mechanism and external appearance of the industrial development of the old industrial base have not fundamentally changed. Although the influencing factors have become more complex, the status of major enterprises and industries has not been shaken, and market forces alone cannot support the sustainable innovation of the old industrial base. Therefore, the problem that the enterprise innovation strategy deviates from the actual realistic needs has always existed. Seen from the outside, the industrial innovation pattern of the old industrial base seems to be locked. Seen from the internal relationship, the old industrial base has always been unable to establish a virtuous circle of mutual promotion between innovation and profitability. The invariance of external phenomena is usually most directly reflected in the spatial dimension, and the distortion of internal relations is usually most directly reflected in the time dimension. Therefore, this paper constructs the identification algorithm of the lock-in effect based on the causal relationship between time series and the heterogeneity of spatial distribution. The specific explanation and use of the algorithm will be carried out in Section 4.2.

At present, industrial innovation in Jilin Province has made great progress, and the awareness of independent innovation has been enhanced. However, on the whole, it still shows a strong and typical lock-in effect, which leads to problems such as immature industrial clusters, lack of effectiveness of general regulatory measures, and difficulties in transforming innovative achievements into economic benefits. These problems hinder the industrial innovation and transformation of the old industrial bases in Jilin Province, and restrict the sustainable development of the industry in the old industrial bases in Jilin Province.

2.2. Three-Stage Industrial Innovation Efficiency Measurement

Old industrial bases often have systematic industrial foundations and strong industrial enterprises. Moreover, the innovation resources of the old industrial base are relatively abundant. The reason why industrial innovation output is lower lies in the low efficiency, which is the explained variable studied in this paper. The efficiency problem is the direct reason why the industrial innovation of the old industrial base gradually lags behind that of the new industrial zone with a weaker foundation, which limits the transformation from comparative advantage to competitive advantage. Many investment plans to promote the development of the old industrial base have failed to achieve the desired results, because the internal mechanism of the old industrial base has not been changed and the efficiency problem has not been solved. Compared with the total index, the efficiency index can better reflect the characteristics of endogenous factors of the old industrial base as a special type of region. Therefore, this study chooses a typical old industrial region to measure the IIE of
each city, and the measurement object is the whole process from the comparative advantage of regional innovation to the competitive advantage of regional innovation.

In the research on innovation efficiency, most studies divide the innovation process into one or two stages. The two-stage model separates the technology R&D stage from the technological benefits generation stage [43,44]. However, the two-stage model is still not comprehensive and does not clearly explain the process involving the integrated utilization of innovation resources, which has a decisive impact on industrial innovation and is very worthy of study. If the analysis of industrial innovation does not consider the process of regional innovation resources being integrated by industrial enterprises, there will be a lack of entry points for the analysis of the relationship between regional evolution characteristics and industrial enterprise innovation. In fact, the economic benefits produced in the innovation process can be regarded as the commodity demand in the innovation field, and the innovation achievements produced in the innovation process can be regarded as the commodity supply in the innovation field. Then the innovation resources that can be used in the process of innovation are factor supply, and the innovation resources that are used by the innovation subject are factor demand, which is an important channel for regional evolution to play an important role in innovation. For a long time, there has been less research on the process of factor supply and demand in the process of innovation. There is a phenomenon that innovation research focuses on the product market and ignores the factor market. If a study wants to analyze the innovative factor market in depth, it must carry out regional research. Taking Jilin Province as an example, colleges and universities have trained a large number of innovative talent, and the government provides financial support for scientific and technological innovation and talent cultivation, which plays an important role in the innovative R&D of industrial enterprises and ensures the stability of their acquisition of innovative resources. Without this support, it is difficult for the optical and mechanical industry and pharmaceutical industry to reach the current level by relying solely on spontaneous processes. The process of integration and utilization of regional innovation resources involves the process of various regional elements of the old industrial base acting on industrial enterprises, and it is a key stage that cannot be ignored. Therefore, the process of transforming various innovation resources into industrial innovation resources in the old industrial base constitutes the first stage of the industrial innovation process. This paper combines the first stage of the industrial innovation process with the two-stage model and proposes a three-stage model including TIR, RIA and IBD.

In the TIR stage, the innovation resources available to industrial enterprises in the old industrial base mainly include local higher education institutions [45,46] and government support in science and education [47,48]. Universities are endogenous local knowledge resources that play a decisive role in the cultivation quality of innovative talent in the regional industry-university-research system and rely on talent to spread the new ideas and methods produced by college research to all links of industrial production. The number of higher education resources available is specifically embodied in the number of universities and full-time teachers. The government’s education expenditure and science and technology expenditure are both components of regional public innovation resources, which directly support the cultivation and development of local innovative talent, reflecting the importance local governments attach to scientific research and development and talent cultivation.

The second stage is the core stage of industrial innovation and the main research object of industrial innovation, that is, the transformation of industrial innovation resources into industrial innovation achievements, which corresponds to the scientific and technological R&D of industrial enterprises. It describes the process through which industrial enterprises invest scientific research funds, set up special scientific research institutions, prepare relevant experimental equipment and allocate R&D personnel to achieve industrial innovation. In this process, industrial enterprises integrate internal R&D talent and funds to produce industrial innovation achievements. This integration and output ability has increasingly become the core means of industrial enterprise competitiveness.
Compared with the RIA stage, the selection of indicators in the third stage is relatively controversial. IBD is the stage involving achieving scientific research advances as important production factors to improve industrial production efficiency. It gives attention to the efficiency of the innovation achievements produced in the previous stage driving economic benefits. This paper takes capital, labor and patent applications as inputs and industrial added value as the output to measure efficiency. To more accurately measure the efficiency of IBD, this paper also compares the efficiency of capital and labor as inputs with the above efficiency to eliminate the influence of factors other than technological innovation.

As shown in Figure 2, the three-stage industrial innovation model depicts the transformation from university resources, government support and other innovation resources to industrial innovation resources, from the investment of industrial innovation R&D personnel and funds to industrial innovation achievements represented by patents, and then from industrial innovation achievements to innovation-driven economic development. The indicators were selected by closely focusing on the industrial innovation process, which helps to improve the accuracy of the IIE measurement. As shown in Table 1, this paper constructs an index system for measuring the efficiency of three-stage industrial innovation.

![Figure 2. Three-stage model of industrial innovation efficiency in the old industrial base.](image)

<table>
<thead>
<tr>
<th>Innovation Stage</th>
<th>Input Indicators</th>
<th>Output Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transformation of innovation resources</td>
<td>Number of universities and colleges (unit) Number of full-time teachers in universities and colleges (person) Local science and technology financial expenditure (10,000 yuan) Local education expenditure (10,000 yuan)</td>
<td>R&amp;D personnel in industrial enterprises (person)</td>
</tr>
<tr>
<td>Research and development of innovative achievements</td>
<td>R&amp;D personnel in industrial enterprises (person) Internal expenditure of industrial R&amp;D (10,000 yuan)</td>
<td>Number of patent applications of industrial enterprises (item)</td>
</tr>
<tr>
<td>Innovation benefits-driven</td>
<td>Total industrial assets (10,000 yuan) Annual average number of all employees (person) Number of patent applications of industrial enterprises (item)</td>
<td>Industrial added value (10,000 yuan)</td>
</tr>
</tbody>
</table>

2.3. Expanded Porter Diamond Model

The industrial innovation process consists of three stages, i.e., TIR, RIA and IBD, that is, the process of moving from the comparative advantage of their own industrial innovation and development to having a competitive advantage. Among the stages, RIA is the core industrial innovation stage. This paper focuses on the factors influencing the efficiency of this stage. The efficiency of RIA is affected by many factors, and the influence mechanism is both regional and comprehensive. The existing indicator system of influencing factors in relevant research is usually made up of some relevant factors lacking a complete set
of analytical frameworks, which usually cannot reflect the economic evolution history of special types of regions. The second stage of industrial innovation is the key connecting point between comparative advantage and competitive advantage. The construction of an influencing factor indicator system should draw on an analysis framework that can take both aspects into consideration. In this paper, Porter’s model, which can include multi-dimensional influencing factors, is selected and expanded to incorporate the idea of regional research into the construction of the influencing factor index system. Porter’s diamond model points out that advanced production factors and industrial clusters lead to competitive advantages. The basic determinants affecting competitive advantage include production factors, demand conditions, related industries and enterprise strategies, the auxiliary factors are opportunity and government [49]. Porter’s diamond model provides a reference for the selection of factors influencing IIE [50]. The competitive advantage theory research gives increasing attention to the interaction between enterprises and regions [51,52]. The competitive advantage of a certain industry in a region is an organic combination of enterprise competitive advantage rather than a mechanical addition. The competitive advantages of enterprises and the integration of their competitive advantages are deeply affected by regional attributes. This is particularly evident in the industrial innovation in the old industrial base.

Corresponding to Porter’s theory of industrial innovation, the main factors affecting the output of industrial innovation can be summarized as the resources available for industrial innovation, the demand for industrial innovation, the supporting industries related to industrial innovation and the innovation strategies of industrial enterprises. On this basis, this paper partially modifies and expands Porter’s diamond model. First, this paper takes IIE as the research object. Efficiency corresponds to the process from input to output. The impact of innovation resources has been considered in the calculation. Second, this paper focuses on the industrial innovation of the old industrial base. The influencing factors and indicators selected should fully reflect the regional characteristics of the old industrial base and the impact of policy support on industrial innovation should be considered. Third, the old industrial base has formed a unique impact mechanism of industrial innovation under the influence of the lock-in effect, which should be reflected in the selection influencing factor indicators. The lock-in effect characteristics of the industrial development of the old industrial base in terms of demand, related industries and enterprise strategy should be the focus. Fourth, cluster plays an important role in Porter’s theory. Clusters have increasingly become the key carriers of innovation competition. For the old industrial base, the industrial cluster structure caused by the lock-in effect and the concentrated allocation of production factors have important impacts on its IIE. The role of the cluster structure in the IIE of the old industrial base should be considered.

The expanded diamond model inherits the comprehensive and detailed analysis framework of the Porter diamond model and can reflect the regional characteristics of the old industrial base under the influence of the lock-in effect. In terms of industrial demand, GDP can comprehensively represent the demand of a city in terms of production and consumption [53]. At the same time, industrial innovation in the old industrial base is deeply affected by foreign trade. Many joint R&D ventures exist in the old industrial base. The dependence on foreign trade (DFT) can represent the extroversion of its economic development. In terms of related industries, the most important aspect at present is the transformation brought about by the intelligent industry under the background of the integration of secondary and tertiary industries. The proportion of tertiary industry output value (PTO) can characterize the development degree of the tertiary industry in a city [54]. Modern industrial innovation is inseparable from the support of producer services, and the employment proportion of information and scientific research practitioners (EIS) can better reflect this. In terms of the innovation strategies of industrial enterprises, whether to focus on absorbing technology for transformation or new technology research and development, the technological transformation trend (TTT) reflects the strategic direction choice of industrial enterprises in the old industrial base, and the average expenditure on
new products development (AEN) can reflect their strategic enterprising strength. In terms of policy support, total financial expenditure (TFE) can reflect the support ability of local governments [55], and the proportion of scientific and technological financial expenditure (PST) can reflect the importance local governments attach to the development of scientific and technological undertakings [56]. In terms of the industrial cluster structure, the average asset size of the industrial enterprise (AIE) and the extent to which industrial enterprises save human resources (EEH) can better characterize the industrial cluster structure under the lock-in effect, in which traditional large enterprises occupy a dominant position and many enterprises are too large. Based on this, as shown in Table 2, this paper constructs the influencing factor index system of IIE in the old industrial base to explore the influencing mechanism of industrial innovation comprehensively and deeply in the old industrial base.

Table 2. Influencing factors of the industrial innovation efficiency in the old industrial base.

<table>
<thead>
<tr>
<th>Element Layer</th>
<th>Index Layer</th>
<th>Computing Method</th>
</tr>
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<tbody>
<tr>
<td>Demand situation</td>
<td>Gross domestic product (GDP)</td>
<td>The final result of production activities of all permanent residents in a certain region within a certain period of time</td>
</tr>
<tr>
<td>Dependence on foreign trade (DFT)</td>
<td>Total imports and exports/GDP</td>
<td></td>
</tr>
<tr>
<td>Related industries</td>
<td>Proportion of tertiary industry output value (PTO)</td>
<td>Tertiary industry added value/GDP</td>
</tr>
<tr>
<td>Employment proportion of information and scientific research practitioners (EIS)</td>
<td>Information and scientific research employment/Urban unit employment</td>
<td></td>
</tr>
<tr>
<td>Enterprise Strategy</td>
<td>Average expenditure on new products development (AEN)</td>
<td>Expenditure for new product development of industrial enterprises/Number of new product development projects</td>
</tr>
<tr>
<td>Trend of technological transformation (TTT)</td>
<td>Expenditure on technology acquisition and transformation of industrial enterprises/R&amp;D internal expenditure</td>
<td></td>
</tr>
<tr>
<td>Policy support</td>
<td>Total financial expenditure (TFE)</td>
<td>Local public financial expenditure</td>
</tr>
<tr>
<td>Proportion of science and technology financial expenditure (PST)</td>
<td>Science and technology financial expenditure/Local public financial expenditure</td>
<td></td>
</tr>
<tr>
<td>Cluster structure</td>
<td>Average asset size of industrial enterprises (AIE)</td>
<td>Total assets of industrial enterprises/Number of industrial enterprises</td>
</tr>
<tr>
<td>The extent to which industrial enterprises save human resources (EEH)</td>
<td>Number of industrial enterprises/Number of industrial employees</td>
<td></td>
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</tbody>
</table>

The factors influencing IIE in old industrial bases can be roughly divided into two categories. One category includes more conventional and applicable factors, including GDP, DFT, PTO, AEN, TFE, PST, etc. This factor selection process takes into account the regional characteristics of the old industrial base in Jilin Province, but it is also suitable for other types of regions. For example, the impact of administrative intervention can be reflected in this part, but the focus on policy is not a unique research perspective of the lock-in effect. The other category includes the influencing factors with distinctive lock-in effect characteristics, including EIS, TTT, AIE, EEH, etc. Although these factors may have some effects on the innovation efficiency of other types of regions, the old industrial base under the lock-in effect usually has some more serious problems. The typical lock-in effect problems, such as the crowding-out effect on emerging industries brought about by the solidification of industrial structure, relatively conservative innovation management and strategies, immaturity of small enterprises and excessive size of large enterprises, are clearly reflected in this part. The indicator system composed of these two types of influencing factors comprehensively considers the general and special laws of the impact mechanism of industrial innovation.
3. Materials and Methods

3.1. Data Sources


3.2. Model Approach

The research method of this paper is based on research questions and an analysis framework. The three parts of the theoretical analysis framework of this paper are the analysis of the lock-in effect of the case region, the division of the stages of industrial innovation, and the construction of the index system of influencing factors, which respectively correspond to the three questions raised in the introduction. The measurement in this paper can also be regarded as three parts, answering three questions respectively.

For the measurement of IIE in the three stages, data envelopment analysis that can handle multiple input and multiple output problems is appropriate. The input and output indicators have been described in the analysis framework, and the selection of specific methods will be described in Section 3.2.1.

For the identification of the lock-in effect, this paper chooses the Granger method to test the causality of time series and the Geographical detectors to test the spatial heterogeneity. The design idea of the algorithm to identify the lock-in effect has been preliminarily described in the analysis framework, and the method will be introduced in Sections 3.2.2 and 3.2.3.

For the demonstration of influencing factors, the selection of influencing factor indicators has been described in the analysis framework. This paper also tests the spatial correlation to determine whether the regression equation needs to consider spatial correlation factors. The panel regression equation is described in Section 3.2.4.

3.2.1. Super-Efficiency Data Envelopment Analysis

Data Envelopment Analysis (DEA) is a common calculation method to measure efficiency. Since the traditional DEA model was created [57], it has derived a variety of types and uses. According to the purpose of use, relevant studies can be divided into the following categories: (1) Some studies try to consider undesired output, so choose SBM and related improved models, usually seen in green development-related research [6,16,58–61]. (2) Some studies are mainly concerned with increment, so choose the Malmquist index, usually seen in production efficiency-related research [58,60,61]. (3) Some studies try to eliminate the effects of environmental factors and random factors, so choose the method of combining DEA and SFA, usually seen in management-related research [62]. (4) Some studies divide the computing object into several stages and try to integrate them into computing, so choose network DEA [63]. (5) Some studies focus on statistical accuracy, so choose bootstrapped DEA [64]. (6) Some studies focus on the efficiency comparison of different DMUs, so choose super-efficiency DEA or combine super-efficiency DEA with other methods [6,16,58,63,65,66].

The research object of this paper is the process of industrial innovation, focusing on the sustainability of industrial competitiveness, differences in efficiency and the impact of environmental factors. The three stages of industrial innovation span a wide range and are macro processes, which are not suitable for combining in the calculation. Therefore, this paper chooses super-efficiency DEA to calculate the IIE of the three stages respectively, as shown below in Formula (1):
\[
\min \theta \\
\text{s.t.} \\
\sum_{j=1}^{n} x_j \lambda_j + s^- = \theta x_m \\
\sum_{j \neq m}^{n} y_j \lambda_j - s^+ = y_m \\
\lambda_j \geq 0, j = 1, 2, \ldots, n \\
s^- \geq 0, s^+ \geq 0
\]

where \( x \) is the input index; \( y \) is the output index; \( \theta \) is the super efficiency value; \( s^- \) is the input relaxation variable; \( s^+ \) is the output relaxation variable; and \( m \) stands for the decision-making unit.

### 3.2.2. Granger Causality Test

The Granger causality test can effectively reveal causal relationships \([67]\) and is suitable for the analysis of time series. This paper stabilizes the time series by means of difference and then uses the Granger test to distinguish the causal relationship between the industrial added value rate (ratio of industrial added value to total industrial output value, IAVR) and IIE to explore the role of the lock-in effect. The calculation method is shown in Formula (2).

\[
y_t = \alpha + \sum_{i=1}^{m} \beta_i y_{t-i} + \sum_{j=0}^{n} \gamma_j x_{t-j} + \mu_t
\]

where \( y \) and \( x \) are time series that have passed the unit root test, \( \alpha, \beta_i, \gamma_i \) are parameters, and \( \mu_t \) is a random variable. If the future value of \( y \) can be predicted according to the past value of \( x \), \( x \) is the Granger cause of \( y \). In this paper, \( x \) or \( y \) represents the IAVR or IIE.

### 3.2.3. Geographical Detectors

Based on the analysis of variance, geographical detectors can measure the influence of different regional types on dependent variables \([68,69]\). Due to the clear spatial layout characteristics and the stability of spatial differences under the lock-in effect, the spatial heterogeneity of the old industrial base is clear, and the use of geographical detectors is more appropriate.

\[
q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma^2_h}{N^2} = 1 - \frac{SSW}{SST}
\]

\[
SSW = \sum_{h=1}^{L} N_h \sigma^2_h, \quad SST = N^2
\]

\( q \) represents the explanation degree of the stratification for the dependent variable. \( h = 1, \ldots, L \) is the stratification of the region. \( N_h \) and \( N \) are the number of units in layer \( h \) and the whole region. \( \sigma^2_h \) and \( \sigma^2 \) is the variance of dependent variables of layer \( h \) and the whole region. \( SSW \) and \( SST \) are the sum of intralayer variance and total variance of the whole region.

### 3.2.4. Panel Regression Analysis

This paper uses multiyear data from many old industrial bases in Jilin Province. Panel regression analysis makes full use of the sample data. Panel regression analysis is used to demonstrate the significance of the influencing factors. The empirical results are more universal than the empirical research of a single city and can give full play to the advantages of intercity-scale research. Therefore, mixed effect panel analysis is adopted in this paper, and the calculation method is shown in Formula (4).

\[
y(i, t) = \alpha + X(i, t) \beta + \varepsilon(i, t)
\]

where \( y(i, t) \) is the explained variable, that is, IIE, \( i \) indicates the individual, \( t \) indicates the time, \( \alpha \) is the intercept, \( X(i, t) \) is the explanatory variable, that is, the influencing factor, \( \beta \) is the regression coefficient, and \( \varepsilon(i, t) \) is the error.
4. Results

4.1. Three-Stage Industrial Innovation Efficiency

Combined with Formula (1), the IIE of the old industrial base in three stages is calculated by the super-efficiency DEA method. The calculation results of the efficiency of the first stage show that from 2007 to 2019, the efficiency of the transformation from regional innovation resources to industrial innovation resources in Jilin Province showed a fluctuating downward trend. As shown in Figure 3, an upward trend did not exist in any cities (prefectures) of Jilin Province, which was consistent with the background of the industrial structure transformation. The efficiency of Changchun fluctuated, and the efficiency value remained relatively stable and had been relatively high. During this period, the industrial structure of all cities (prefectures) in Jilin Province changed from the structure dominated by the secondary industry to the structure dominated by the tertiary industry. Regional innovation resources had more transformation directions, which contributed to the diversification of knowledge, but also caused problems such as insufficient factor market scale of industrial innovation. Except for Changchun, most areas of Jilin Province were not rich in innovation resources, and industrial enterprises’ ability to integrate and utilize local regional innovation resources was weakened, which promoted the expansion of innovation differences between regions.

![Figure 3](image-url)

**Figure 3.** The efficiency of the transformation of industrial innovation resources in the cities (prefecture) of Jilin Province: (a) the efficiency of TIR in 2007, (b) the efficiency of TIR in 2011, (c) the efficiency of TIR in 2015 and (d) the efficiency of TIR in 2019.

The calculation results of the efficiency of the second stage show that from 2007 to 2019, the overall efficiency of RIA in Jilin Province rose during the fluctuation, then remained stable, and then rose again. As shown in Figure 4, most cities (prefectures) did not show a downward trend. The innovation efficiency of Baicheng had an obvious
upward trend, gradually surpassing other regions, and had gained significant advantages. The RIA is the core industrial innovation stage. The improvement of the efficiency of the second stage of the old industrial bases in Jilin Province reflects the industrial innovation transformation achievements. In terms of horizontal comparison, the efficiency of RIA in Jilin Province initially evolved into a pattern of high in the east and west and low in the middle. Areas with weak industrial innovation resources had higher efficiency, and eventually, the efficiency evolved into a pattern of high in the west and low in the east. The efficiency of the central and western regions increased significantly, and the difference in efficiency widened significantly. This paper further used the Global Moran’s I to test the spatial autocorrelation of the efficiency values every year and found that the spatial autocorrelation was not significant, and there was no obvious spatial spillover effect. This shows that although the efficiency of the second stage of the old industrial bases in Jilin Province had increased significantly, the overall development level was still low.

The calculation results of the efficiency of the third stage show that from 2007 to 2019, the overall pattern of the efficiency of IBD in Jilin Province gradually changed from high in the East and West and low in the middle to an overall homogeneous distribution. As shown in Figure 5, the efficiency of Baicheng and Baishan was relatively high, the efficiency change of Changchun showed a steady upward trend, the efficiency of Jilin, Tonghua and Yanbian fluctuated at a low level, while the efficiency value of other regions showed a slight downward trend. Through comparison, it is found that in the vast majority of years from 2007 to 2019, whether industrial enterprise patents are used as input or not, the output efficiency of industrial added value in Jilin Province and all cities (prefecture)
has little change. It can be seen that all cities (prefectures) have failed to make full use of industrial innovation to drive economic growth, and the driving effect of industrial innovation achievements on economic benefits is weak. In addition, from the perspective of the overall environment, the overall technology transfer in Northeast China shows a trend of outflow to domestic developed regions, and the local transformation is weak [70]. The industrial innovation activities of the old industrial base in Jilin Province still deviate from their realistic needs, which is a typical manifestation of the lock-in effect. This explained why the efficiency of the first stage of industrial innovation in the old industrial base of Jilin Province had declined. Under the background of the imbalance between supply and demand in the product market, industrial innovation was difficult to obtain profits, and the factor market naturally shrank as a result.

Figure 5. The efficiency of innovation benefits-driven in the cities (prefecture) of Jilin Province: (a) the efficiency of IBD in 2007, (b) the efficiency of IBD in 2011, (c) the efficiency of IBD in 2015 and (d) the efficiency of IBD in 2019.

4.2. Identification of the Lock-In Effect

The core mechanism of the lock-in effect is the self-reinforcing mechanism, and the basis for supporting self-reinforcing is profitability. The old industrial bases usually have relatively stable profits, resulting in a lack of motivation for self-innovation in some old industrial bases. In this situation, the self-reinforcing role prevails, and there may even be a negative interaction between profit and innovation. Therefore, a key to identifying the lock-in effect is to distinguish the causal relationship between industrial profitability and IIE. In terms of index selection, IAVR can reflect the position of the industry in the value chain of production links, the competitive advantage of added value and the ability to obtain profits. Through the Granger causality test, this paper analyses the relationship between IAVR and IIE of the old industrial base in Jilin Province to identify the lock-in
The results show that from 2007 to 2019, on the provincial scale, the change in the efficiency of RIA leads to a reverse change in IAVR. The IAVR of Jilin City and Tonghua City will cause a change in the same direction in the efficiency of TIR, and the efficiency of IBD of Baicheng City will cause a change in the reverse direction in IAVR.

The old industrial base of Jilin Province has failed to form a virtuous circle in which the R&D of industrial innovation achievements and industrial profits promote each other. Even at the provincial level, there is an unhealthy circle of hindering relations, which is a typical manifestation of the lock-in effect. The improvement of IIE should contribute to an increase in industrial profitability, and the enhancement of industrial profitability should contribute to industrial innovation. If this mutually promoting relationship cannot be formed, it is difficult for the old industrial base to develop sustainably. Industrial innovation in Jilin Province has not yet brought obvious profits to industrial development, and industrial profits have only resulted in stronger lock-in rather than more positive innovation. The old industrial base is relatively firmly locked in the old path, and the transformation of industrial innovation is hindered by the lock-in effect.

After identifying the internal mechanism of the lock-in effect, this paper further describes the external phenomenon of the lock-in effect more intuitively. The most intuitive phenomenon of the lock-in effect is reflected in the change in the spatial pattern of industrial innovation. Based on the input and output indicators of the first stage of industrial innovation in 2007 and the input and output indicators of the third stage of industrial innovation in 2019, this paper uses the systematic clustering analysis function of SPSS 22.0 to form two classification systems for cities (prefectures). Based on the input and output indicators of the first stage of industrial innovation in 2007, cities (prefectures) in Jilin Province can be divided into four categories: Changchun; Jilin; Siping, Baicheng, Tonghua, Songyuan, Yanbian; Liaoyuan, Baishan. This reflects the differences in the accumulation of innovation resources in cities (prefecture) in Jilin Province at the beginning of the stage in which multiple factors exerted influence together, which is an intuitive reflection of the evolution results of long-term industrial innovation. Based on the input and output indicators of the third stage of industrial innovation in 2019, cities (prefecture) in Jilin Province can be divided into three categories: Changchun and Songyuan; Siping, Liaoyuan, Tonghua, Jilin; Baicheng, Yanbian, Baishan. This reflects the differences between the final industrial economic benefits obtained by cities (prefecture) in Jilin Province. A category is relatively homogeneous within, and different categories are relatively heterogeneous. Furthermore, taking the output and efficiency of the second stage of industrial innovation in cities (prefecture) in Jilin Province from 2007 to 2019 as the explanatory variables, this paper adopts geographical detectors to calculate. The results show that, in terms of output, the heterogeneity of innovation resources accumulation in 2007 had a significant impact on the number of patent applications of industrial enterprises in each year, and the degree of explanation was more than 95% in each year. The difference in industrial economic results in 2019 had no obvious impact on the output of each year. In terms of efficiency, the heterogeneity of industrial economic results in 2019 had a significant impact on the efficiency of RIA in 2013 and 2015, and the difference in innovation resources accumulation in 2007 had no obvious impact on the efficiency of each year.

It can be seen that industrial innovation in the old industrial base of Jilin Province shows a very strong lock-in effect. The previous regional evolution played a decisive role in the subsequent industrial innovation achievements, which once again proved the significance of studying the IIE of old industrial bases based on the lock-in effect. It also proved the necessity of bringing the stage of TIR into the scope of industrial innovation research to build a three-stage model of industrial innovation. In addition, the empirical results are consistent with the measurement results of the third stage in the previous part of the article and the results of Granger’s analysis. The link between industrial innovation achievements and industrial economic benefits of the old industrial base in Jilin Province is weak and cannot produce a virtuous cycle. At the same time, it also shows that improving
the efficiency of RIA plays an important role in breaking the lock-in effect and improving industrial economic benefits.

The analysis and identification of the lock-in effect of the old industrial base in this paper are shown in Figure 6. To sum up, the old industrial bases in Jilin Province show a significant lock-in effect on the industrial innovation mechanism and performance. It is scientific and necessary to study the industrial innovation of the old industrial bases in Jilin Province based on the lock-in effect. As the lock-in effect is the most distinctive evolutionary feature, taking the lock-in effect as the research perspective is conducive to combining the regional evolution characteristics with the industrial innovation performance and deepening the understanding of the impact mechanism of industrial innovation.

**Figure 6.** Schematic diagram of analysis and identification of lock-in effect.

### 4.3. Empirical Analysis of Influencing Factors

Combined with Formula (4), the empirical results are shown in Table 3 through the mixed effect panel regression method. First, the expanded Porter model considering the lock-in effect can better explain the influence mechanism of the efficiency of RIA. The industrial innovation of the old industrial base of Jilin Province is affected by both conventional influencing factors and lock-in effect factors. Second, foreign trade can promote the industrial innovation of the old industrial base in Jilin Province, while an increase in the total local economy may weaken the driving force of industrial innovation. The industrial products of the old industrial base in Jilin Province are still mainly exported to external markets. Third, the combination of industrial innovation and producer services in the old industrial base of Jilin Province is still insufficient, and the supporting role of the tertiary industry in industrial innovation is not strong, which is consistent with the innovation efficiency calculation results in the first stage. Fourth, the introduction of advanced technology and equipment renewal by industrial enterprises in the old industrial base of Jilin Province is significantly conducive to improving the efficiency of RIA, while excessive investment in new product development projects will reduce the efficiency, indicating that the industrial innovation transformation of the old industrial base of Jilin Province should be gradual. Fifth, the financial support of local governments is conducive to improving the efficiency of RIA. There is still room for improvement in the use of scientific and technological financial expenditures. Local governments play a significant role in the change in the efficiency of RIA. Sixth, if the industrial enterprises in the old industrial base of Jilin Province improve the EEH, it will help to improve the efficiency of RIA. The number of assets has no significant impact on efficiency.
The base of Jilin Province is significantly conducive to improving the efficiency of RIA, while excessive investment in new product development projects will reduce the efficiency, indicating that the industrial innovation transformation of the old industrial base of Jilin Province should be gradual. Fifth, the financial support of local governments is conducive to improving the efficiency of RIA. There is still room for improvement in the use of scientific and technological financial expenditures. Local governments play a significant role in the change in the efficiency of RIA. Sixth, if the industrial enterprises in the old industrial base of Jilin Province improve the EEH, it will help to improve the efficiency of RIA. The number of assets has no significant impact on efficiency.

Table 3. Empirical results of factors influencing the efficiency of research and development of innovative achievements.

<table>
<thead>
<tr>
<th>Element Layer</th>
<th>Index Layer</th>
<th>Parameter Estimate</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept term</td>
<td>Intercept term</td>
<td>$3.70 \times 10^{-1}$</td>
<td>0.017</td>
</tr>
<tr>
<td>Demand situation</td>
<td>GDP **</td>
<td>$-1.25 \times 10^{-8}$</td>
<td>0.020</td>
</tr>
<tr>
<td></td>
<td>DFT *</td>
<td>$3.56 \times 10^{-3}$</td>
<td>0.054</td>
</tr>
<tr>
<td>Related industries</td>
<td>PTO *</td>
<td>$-7.10 \times 10^{-3}$</td>
<td>0.076</td>
</tr>
<tr>
<td></td>
<td>EIS</td>
<td>$-2.44 \times 10^{-4}$</td>
<td>0.859</td>
</tr>
<tr>
<td>Enterprise Strategy</td>
<td>AEN **</td>
<td>$-7.16 \times 10^{-5}$</td>
<td>0.018</td>
</tr>
<tr>
<td></td>
<td>TTT ***</td>
<td>$3.71 \times 10^{-6}$</td>
<td>0.000</td>
</tr>
<tr>
<td>Policy support</td>
<td>TFE **</td>
<td>$1.08 \times 10^{-7}$</td>
<td>0.020</td>
</tr>
<tr>
<td></td>
<td>PST</td>
<td>$-5.35 \times 10^{-2}$</td>
<td>0.163</td>
</tr>
<tr>
<td>Cluster structure</td>
<td>AIE</td>
<td>$2.52 \times 10^{-7}$</td>
<td>0.520</td>
</tr>
<tr>
<td></td>
<td>EEH **</td>
<td>$3.09 \times 10^{-2}$</td>
<td>0.017</td>
</tr>
</tbody>
</table>

Notes: ***, **, and * represent a significant result under the 1%, 5% and 10% confidence levels, respectively.

Combined with all the previous calculations and statistics, the impact mechanism of industrial innovation in the old industrial base can be summarized as shown in Figure 7. It can be seen that the lock-in effect can affect industrial innovation through multiple dimensions, but not all dimensions have the same impact direction. Therefore, we should not simply define the impact of the lock-in effect on industrial innovation as good or bad but should analyze the action mechanism of the lock-in effect on industrial innovation in detail.

![Figure 7. Schematic diagram of influence mechanism of industrial innovation in old industrial base.](image-url)
5. Discussion

The lock-in effect is the medium for this paper to study the impact of industrial evolution history on industrial innovation. This paper has verified the existence of the lock-in effect, and the lock-in effect is clearly distorting the industrial innovation of the old industrial base in general, but the purpose of this paper is not to give a good or bad evaluation of the lock-in effect. This paper attempts to dissect the action mechanism of the lock-in effect on industrial innovation in detail to explore the law of industrial innovation in the old industrial bases, so as to provide countermeasures for sustainable development. When reviewing the history of industrial evolution in the case area, this paper summarizes four channels through which the lock-in effect has an impact on industrial innovation. The impact of these dimensions on industrial innovation has been proven to be significant in the measurement part, but the direction and degree of impact of each dimension are different. On the one hand, the lock-in effect hinders the supply and demand matching of industrial innovative product markets. It is difficult for the achievements of industrial innovation to be quickly transformed into local productivity. The lack of driving ability of industrial innovation to industrial economic benefits will eventually lead to the shrinkage of the industrial innovation factor market. On the other hand, the lock-in effect plays a complex role in the industrial innovation environment. For example, policy support has proved indispensable. Moreover, the empirical results show that although too large enterprises need to be streamlined, industrial enterprises should not adopt overly radical innovation strategies and the transformation of economic structure should also avoid radicalization. It can be seen that the cautious conservatism brought by the lock-in effect is not necessarily a negative effect.

Through the above summary of the mechanism of the lock-in effect, we can see how the regional characteristics caused by the industrial evolution history of the old industrial base affect industrial innovation. First, the long-term industrial evolution has formed some stable innovation subjects as well as interest subjects, leading to the lack of internal innovation enthusiasm and the loss of flexibility of the external structure. Second, the overly complex and rigid mechanism caused by long-term evolution has lengthened the distance between industrial innovation and industrial profit, thus leading to the waste and loss of regional innovation resources. Third, in the long-term evolution, the old industrial base has formed a certain adaptability, and too radical changes may be counter-productive. Therefore, it is unlikely to achieve good results by increasing investment alone to promote industrial innovation in the old industrial bases. The old industrial bases need to be properly changed. The measures should not only change the existing pattern and increase innovation vitality, but also not be too radical, which will damage the old industrial bases’ protection against external competition. But in fact, it is very difficult to achieve such an appropriate level, because various factors are often intertwined and difficult to separate. This is why the innovative development of the old industrial base is a globally recognized problem.

6. Conclusions and Advices

6.1. Conclusions

This paper studies the influence mechanism of industrial innovation in the old industrial bases and combines the industrial evolution history with industrial innovation with the lock-in effect as the link. Therefore, this paper creatively constructs a three-stage model of industrial innovation, a lock-in effect identification method, and an extended Porter model. Based on the review of the evolution history of industrial innovation in the case region, the measurement of the efficiency of industrial innovation, the identification of the lock-in effect and the demonstration of the influencing factors, the following three conclusions are drawn in this paper.

First, according to the calculation, the attraction of industrial enterprises in Jilin Province to regional innovation resources is declining. The efficiency of technological innovation of industrial enterprises in most cities has improved, but the differences be-
tween cities are widening and the innovation links between cities are weak. The ability to transform industrial innovation achievements into economic benefits is generally weak. This is in line with the characteristics of IIE under the lock-in effect. The lack of the ability to profit through innovation and the lack of ability to attract resources for innovation form an unhealthy circle.

Second, the empirical results show that the industrial innovation of Jilin Province does face the restriction of the lock-in effect and has not been able to get rid of the path-dependent growth. The internal relationship is distorted, and the external pattern is solidified. The temporal and spatial characteristics of the lock-in effect are significant. It is scientific and necessary to study the industrial innovation of the old industrial bases based on the lock-in effect.

Third, through the empirical analysis of the influencing factors, this paper finds that the industrial innovation of the old industrial bases in Jilin Province is indeed affected by both conventional influencing factors and lock-in effect factors. The impact mechanism is complex, and the lock-in effect cannot be simply summarized as a negative impact. The development of foreign trade, the introduction of advanced technology and equipment renewal, the increase in financial support from local governments and the increase in the extent to which industrial enterprises save human resources are conducive to improving innovation efficiency. The increase in the local economic aggregate, the increase in the proportion of the tertiary industry and the increase in average development funds for new products have negative effects on innovation efficiency. The proportion of employees in producer services, the proportion of scientific and technological fiscal expenditures and the average assets of industrial enterprises have no significant impacts on innovation efficiency.

In general, by applying the regional research thinking in geography to the research on the IIE of the old industrial base, this article finds out how the regional characteristics formed by the long-term industrial evolution affect industrial innovation. The typical characteristics of industrial innovation in the old industrial base are the insufficient innovation motivation caused by the distorted internal mechanism, the inefficient utilization of innovation resources caused by the deviation from the market, and the self-protection mechanism with high requirements for policy fineness.

6.2. Policy Advice

Through sorting out the evolution history of industrial innovation in Jilin Province, this paper summarizes the multi-dimensional mechanism of the lock-in effect, which also exists in many old industrial bases around the world. The empirical results show that although the lock-in effect generally distorts the innovation mechanism of the old industrial base, not every dimension of the lock-in effect will limit innovation efficiency, and the transformation of the old industrial base needs high precision policies as a guarantee. Therefore, this paper proposes the following four suggestions.

First, the old industrial base must build a direct channel connecting industrial innovation and market demand. The original motivation should be to make profits in the market, so as to promote the innovation of industrial enterprises and attract regional innovation resources. It should be a top priority for the old industrial base to make full use of the existing regional innovation resources.

Second, due to the remote location, fierce competition, and industrial iteration, it is unrealistic for the old industrial base to rely solely on market regulation for industrial innovation, which may lead the old industrial base into a dilemma similar to the rust belt in the United States. Therefore, the policy to support industrial innovation in the old industrial base should be strengthened, but the relationship between market factors and non-market factors should be well coordinated.

Third, many old industrial bases do not have the conditions to take the new industry as the leading industry in a short time. Local governments and local enterprises should avoid overly radical strategies. For most old industrial bases, it is more realistic to gradually solve the innovation problems of traditional strong industries.
Fourth, cultivating small enterprises is very important for the industrial innovation of old industrial bases. On the one hand, small enterprises can force large enterprises to improve management efficiency. Entrepreneurs are often innovators themselves, and the improvement of the innovation atmosphere should not be separated from the improvement of the entrepreneurial atmosphere. On the other hand, most of the small enterprises generated in the old industrial bases are related to the original industries, which may develop into new supporting industries that can promote industrial upgrading.

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