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Research on Innovation Theory and Measurement

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Abstract: Innovation is a critical driver of economic growth. This paper reviews the evolution of the concept of innovation and measurement methods. It explores the connection between process-oriented innovation models and the development of measurement methods. The classification of innovation measurements based on various typologies is discussed. Finally, in the context of digitization and globalization, the paper examines future prospects for innovation measurement. The main conclusions are:①The evolution of societal practices has driven the ongoing development of the concept of innovation and led to continuous refinement in measurement methods.②The inherent limitations of traditional indicators will be partially resolved in the era of big data.

1. Introduction

As early as 1912, Joseph Schumpeter proposed in The Theory of Economic Development that innovation is an internal force that disrupts equilibrium and promotes social progress. He argued that static economic research focusing on resource allocation is insufficient, as economic development is a qualitative process driven by innovation. Although initially excluded from mainstream economics, innovation theory gained prominence in the 1980s with the resurgence of evolutionary economics led by Nelson[3]. Over time, the significance of innovation has been widely acknowledged.

For decades, China's economic growth has relied heavily on factors such as investment and capital accumulation. However, since 2010, global competition and economic challenges prompted a shift towards innovation-driven development. In 2012, the 18th National Congress of the CPC emphasized the importance of science and technology and outlined a strategy for innovation-driven development. By the 19th National Congress, innovation had been firmly established as a key driver of development and a strategic pillar of the modern economic system.

The measurement of innovation has long been a focal point in innovation research. Understanding the relationship between innovation and economic growth at the firm, regional, and national levels is essential for policymaking and the successful construction of an innovative nation. However, the unique nature of innovation—its diversity, dynamism, and systemic characteristics—makes measurement challenging[1][2][7]. Some argue that innovation is inherently immeasurable, while others believe that its complexity does not preclude meaningful analysis[4].

This paper examines the evolution of the innovation concept and measurement methods,

focusing on their interwoven development. The final sections address the challenges and trends in innovation measurement within the current context and propose future directions.

2. Concept of Innovation and Innovation Models

2.1 Concept of Innovation

Schumpeter put forward the concept of "innovation" in 1912. Examples of innovation he proposed include: new products, new production methods, new sources of supply, new markets, and new forms of enterprise organization. He defined innovation as the "rearrangement" of existing resources. He also believed that it was the "entrepreneurial function" that led to this reintegration of resources. It can be seen that Schumpeter's definition of innovation covers a wide range, including many aspects of technological innovation and non-technological innovation. The concept of innovation has been developing and changing since Schumpeter. In general, innovation is increasingly recognized as a new mode of production and the application of new technology to bring good economic benefits to people. With the development of practice, innovation theory has been continuously expanded and improved, and the understanding of the connotation of innovation has also been expanded and deepened. Specifically, there are several perspectives to look at it: (1) The changes in the connotation of innovation have been summarized from the changes in the definition of the concept of innovation in the Oslo Manual of OECD from the first edition to the fourth edition.[5] (2) From the continuous evolution of innovation model to see the change of innovation concept; (3) from the perspective of the scope of innovation concept: innovation has experienced three stages from the Schumpeter stage to the generalized innovation, to the technological innovation and then to the generalized innovation. [6][7][8] On the whole, the definition of innovation in Oslo Manual is more inclined to practical application and more inclined to the construction of innovation measurement index system. At the same time, its definition is based on the development of innovation theory and the evolution of innovation model.From the perspective of innovation scope, the innovation theory is divided into generalized innovation, technological innovation and then generalized innovation, which can only analyze part of the connotation of innovation, but can not highlight the systematic and dynamic characteristics of innovation in a complete system, and can not reflect the difference between the first generalized innovation and the second generalized innovation. Change from the existing literature on innovation connotation understanding there are two main ways: One is the definition of innovation in some authoritative texts (such as the Oslo Manual); the other is to explain the changes in the cognition of the connotation of innovation by combing the innovation theory and innovation model. This paper chooses to describe the changes in the connotation of innovation from the perspective of innovation model changes; the other is that the response of innovation model to innovation connotation is more comprehensive, systematic and profound. Second, the innovation model is a generalization of cognitive and innovation theory, authoritative text in the definition of innovation is based on a certain stage of cognition and innovation theory, as a result, from the innovation model for innovation connotation of cognitive change, can make more clear logic chain complete[9].

2.2 Innovation Models

The influential classical innovation theories can be systematically classified from the five dimensions of applicability, process, knowledge, condition and leadership. Models divided by different classification methods have different functions. Innovation models based on the applicability perspective mainly focus on discussing the matching relationship between existing enterprises, new enterprises and progressive or radical innovation.[10] The innovation model based

on applicability perspective mainly focuses on the matching relationship between existing enterprises and new enterprises and progressive or breakthrough innovation. The division of process perspective divides innovation into stages and discusses the essential characteristics of innovation in each stage and the evolution law of technology in each stage. From the perspective of knowledge, the relationship between product structure and knowledge types and the influence of different knowledge content of products are discussed. The innovation model from the conditional perspective tries to identify the factors that affect the success of innovation from the micro and macro perspectives except technical factors. Innovation models from the perspective of leadership focus on the influence of managers, leaders and organizational framework on the mechanism and success of innovation. Process under the perspective of innovation model has a different sort[7]: (1) Utterback and Abernathy model based on the different stages of technology development to describe the dynamic process of enterprise and industry, the model of innovation includes floating phase, transition phase and professional stage three. (2) Tushman - Rosenkop model that can be based on the complexity of the technology innovation and evolution stages divided into technical stage of discontinuity, gestation period, the dominant design, incremental innovation; (3) Foster S curve model based on technical development speed of technological innovation can be divided into infancy stage, healthy and strong, saturated three stages. 4) Rothwell (1994) distinguished five generations of innovation models: technology push, demand pull, integration model, system integration model and network model; Rothwell's 5-generation innovation model is selected here, because the 5-generation model is more comprehensive and systematic in describing the innovation of innovation, and the interpretation of innovation in the Oslo Manual and other documents is closer to the 5-generation model, and the 5-generation model has been widely recognized in the field of innovation measurement. On the basis of the 5-generation model, Kotsemir et al. proposed the 6th generation innovation model. In general, the evolution trend of innovation models is from linear to systematic, and there are three types: linear model, innovation feedback model and innovation feedback model[10] .

1) Linear models of innovation

Rothwell's first-generation technology-push model and second-generation demand-pull model are typical innovation linear models [11]. This model assumes that innovation activities follow the linear development process of "basic research-applied research-commercial production-going to market", and the biggest difference between the two generations of models is the source of technological innovation. The first generation believes that the main source of technological innovation power is technology promotion, and the second generation believes that demand pull brings power to technological innovation. Freeman and Godin believed that the linear model of innovation was first mentioned in Bush's book Science—The Frontier without Limits[11]. The technologydriven innovation model emphasizes the importance of basic research and development, and believes that it is mainly the development of basic science that drives innovation, such as nuclear energy and space technology. The demanddriven innovation model emphasizes more on the role of market demand in innovation. For example, during World War II, Germany's urgent need for "synthetic" materials led to the enthusiasm of IG-Law and other chemical companies for research and development, and the post-war economic demand for military aerospace in the United States stimulated a series of innovations based on Bell's semiconductor scientific breakthrough. It helped create the first computer. According to the linear model of innovation, innovation is a linear and gradual process and it can be argued that innovation efforts are mainly focused on research and development (although demand-pull models emphasize the enthusiasm of the market), and how the results are translated into new products or services is assumed to be automatic "black box".

2) Innovation feedback model

Rothwell's third-generation interaction model and the fourth-generation Research and

development Design engineering Manufacturing Market development Sales Market Demand Research and development Production Salesintegrated model both belong to innovation feedback models. After a period of debate about whether the driving force of innovation is technology-driven or demand-driven, Nelson, Winter and other scholars have integrated the views of both sides, At first, both demand-pull and technology-pull were regarded as the driving force of innovation, and they played a role in innovation together. Innovation is beginning to be seen as the result of an "interaction model" in which new knowledge is generated in combination with existing knowledge. Because the model holds that new ideas can be generated in any one sector, connections between different sectors are crucial for innovation. In this model, enterprises have a sequence problem in the selection of existing knowledge and external knowledge. For the technical problems encountered, they first look inward to find out whether existing knowledge can solve them. When the existing knowledge cannot solve the problems encountered, they will start to consider creating new knowledge. At this time, technological innovation is no longer regarded as a separate activity of a certain enterprise, but is considered to be carried out in the innovation network.

3) Innovation system model

Some countries have increased R&D investment, but there are huge differences in the innovation effect. The innovation measurement method based on linear model has been challenged. In the late 1980s, a group of scholars, including Freeman, Lundelwald and Nelson, put forward the concept and theory of national innovation system from the perspective of system theory on the basis of studying the innovation activities of Japan, and analyzed various factors affecting the innovation capacity of economies. Since the emergence of this theory in the 1990s, theorists and policy makers have paid more attention to the innovation capability at the macro level. According to the theory of national innovation system, national innovation system is a network system formed by the interaction between the relevant subjects of innovation activities and various relevant institutions and policies in the process of promoting innovation activities. The fifth generation system integration and network model proposed by Rothwell belongs to this category. The fifth generation model holds that in addition to the knowledge sharing and interaction between different units within the enterprise, the connection between the enterprise and other knowledge creation institutions (such as universities, research institutions, users and suppliers is also necessary[14].

3. The relationship between innovation theory and innovation measurement methods

Clarifying the connotation of innovation is the basis of innovation measurement. With the deepening of people's cognition of innovation, the connotation of innovation is constantly enriched, and the methods of innovation measurement are constantly changing. According to Godin's point of view, the development process of innovation measurement since the 1950s can be divided into four stages: (1) In the 1950s and 1960s, the selection of indicators of innovation measurement is mainly related to innovation investment such as R&D investment, human capital, capital intensity and so on. [12] 2) In the 1970s and 1980s, the index system of innovation measurement added the content of innovation output, such as technology patents and innovative products. 3) Since the 1990s, innovation measurement has gradually shifted to the innovation index system based on survey statistics and public data. 4) Since the 21st century, innovation measurement has increasingly emphasized the role of knowledge indicators, innovation networks, innovation conditions, economic needs, public policy environment, and cultural factors on innovation success. It can be seen that the development of innovation measurement is consistent with the evolution of innovation models and the development of innovation theories. Through the comparative analysis of the development stage of innovation measure and the evolution of innovation model, it can be seen that there is a certain correlation logic among innovation cognition, innovation theory and innovation

measure. Specifically, they include: Specific innovation theories are rooted in the development of social practice. The development of social practice leads to changes in innovation activities and enriches people's cognition of the connotation of innovation, which further promotes the continuous improvement of innovation theories, which in turn provides guidance for the practice of innovation measurement. It also directly influences the data collection method of innovation measurement index and the establishment and use of innovation measurement method.

4. Challenges in Measuring Innovation

4.1 The connotation of innovation is constantly changing

Innovation means novelty, which is a kind of universal activity of dynamic system. With the development of science and technology constantly, digitalization and globalization development trend of change the form of innovative activities, the connotation of innovation is more and more rich, this brought challenges to innovation measure. There are more and more ways to acquire knowledge, and the way and degree of contact between various departments are also changing constantly. Innovation system more complex, its characteristic is more and more difficult to grasp, the traditional index system is facing the test of reality. Today's society is becoming more and more knowledge-intensive and has become a knowledge-intensive society, and innovation is increasingly taking on diversified forms. The current innovation survey is not enough for non-technical innovation and innovation network. At the same time, due to the wide application of digital technology and information technology, the business process and transaction mode of various innovation subjects such as enterprises are constantly changing. Innovation under the background of digitalization is constantly expressing new forms of innovation. At present, R&D and innovation also have more characteristics of international cooperation, and research institutions of different countries and enterprises are more and more frequently conducting cooperative research through direct or indirect international cooperation and other different ways. Therefore, the globalization factor should be taken seriously in the process of innovation measurement.

4.2 Data quality of innovation measurement

1) Data on R&D expenditure

Exactly how much about the definition of R&D input can be included in the, what types of activities can be included in the different statistical caliber have different rules. At the same time, the whole R&D data only measures the input part of innovation, and not all innovation is based on R&D. Therefore, R&D data has certain limitations [4] as an innovation indicator. First, since different nations have different statistical scope of r&d spending, investigate the countries according to different standards, and may have different estimation and evaluation methods [21] . The way R&D expenditure is divided by industry and geography also affects the compar [10] ability of data across countries.

2) Patent data

A patent is an open contract between the inventor and the government, which grants the applicant the right to monopolize the use of a technical invention for a certain period of time. The emergence of the patent system is an incentive mechanism for the creation of new economically valuable knowledge, as well as a knowledge diffusion mechanism for information. There is debate about the merits of the patent system, but as an indicator of innovation output, patents collect detailed information about new technologies and organize it into a long-term, continuous public record of inventive activity. Patent data is a detailed record of technology information, has centuries of records and is freely available, making patents an important indicator of innovation. But patents

also have some disadvantages as an indicator of innovation, the main one being that they measure invention rather than innovation, and that they signal the emergence of new technological principles rather than new business innovations. And many of the patent categories have no technical or economic significance at all. At the same time, not all inventions will be patented, and some will protect their own interests through trademarks, encryption and other methods. Regulations on patents vary from country to country, making it difficult to compare data in different patent databases.

3) Data mining methods

The emergence and development of digital technology is of great significance to the collection and use of data related to innovation measurement. Compared with survey methods, using digital technology ideas to make full use of data generated in various activities such as administrative records, transactions, advertising and social networking is more convenient, cheaper and more datarich. At the same time, data is naturally generated in all kinds of social activities. Compared with survey data, natural data is less subject to people's subjective influence and therefore more objective. However, data mining methods also face some difficulties in the application of innovation measurement, such as the selection of data, the selection of data processing methods and how to explain to the public.

5. Progress and Prospects in Innovation Measurement Methods

5.1 Progress in Innovation Measurement Methods

Starting from different perspectives, it will lead to the selection of different indicators and the use of models. Although the design of specific innovation measurement for different situations can better measure the innovation capability of the tested object, it will bring about the comparison problem of data of different enterprises and regions. The difference of cognitive perspective may lead to the deviation of researchers' understanding of the concept of innovation, and then make them different in the processing of innovation measurement data and the evaluation of processing results. The use of innovation data is limited to certain enterprises or focuses on certain aspects, which makes the comparison of innovation measurement data and results more difficult, resulting in the waste of data that cannot be fully utilized.

5.2 Prospects in Innovation Measurement Methods

Since the 21st century, the cognitive level of innovation in academia has been continuously improved to a new height. The existing innovation measurement methods and indicators are not applicable, and they are not comprehensive enough to describe the complex interaction of innovation subjects and the overall picture of innovation network relations. Adapting to the era of big data, richer data provide more data sources for innovation measurement, enrich the data of the old index system and find new indicators related to innovation. Data mining and analysis play an important role in improving the existing innovation measurement methods and establishing new innovation measurement methods. In practice, some papers have used big data to expand the perspective of innovation measurement index data, such as text mining, complex social network analysis and other data and big data processing methods to conduct empirical analysis on the innovation ability of related objects. Shapira and Youtie [13] explored the method of extracting knowledge and innovation-related information of a specific industry in a certain region by means of data mining, and demonstrated it through four cases. Zhao Yan and Meng Qingshi [12] strengthened the cognition of innovation network structure by mining and analyzing the characteristics of network subgroup density and subgroup overlap in 11 Chinese high-tech industry alliances, and

then evaluated and measured the innovation capability of hightech enterprises on this basis.

6. Conclusions

To conclude, innovation is an important source of economic growth. Based on the evolution of innovation concept and innovation measurement methods, this paper reviews the relationship between innovation model from process perspective and innovation measurement. Some classifications of innovation measures according to different classification methods are described. Finally, combining with the background of digitalization and globalization, the paper puts forward the prospect of innovation measurement. The following propositions are drawn: (1) The development of social practice makes the concept and connotation of innovation develop continuously, and then the methods of innovation measurement are constantly adjusted and improved. (2) The old indicators have inherent defects, which will be solved to a certain extent in the era of big data. In short, innovation plays a great role in economic development, economic competition and the improvement of people's quality of life. A perfect innovation measurement method is of great significance to innovation evaluation, innovation policy formulation and rational allocation of resources. Different innovation measurement methods at present have some defects. At the macro level, how to solve the comparability of data between countries, and how to develop a more appropriate and directional index system according to different industries and different types of enterprises at the micro level need to be solved in the future practice. In a knowledge-intensive society, with the rapid development of digital technology, information exchange, upload and access are more convenient. How to use big data technology more scientifically to help improve the old innovation indicators and develop new measurement methods needs to be paid attention to.

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