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DEVELOPING A ROBUST FRAMEWORK FOR NATIONAL INNOVATION SYSTEMS

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Abstract: This article delves into the theoretical evolution and comprehensive framework construction of the national innovation system to provide valuable insights and guidance for its practical implementation. Over time, the concept and practice of the national innovation system have evolved, initially considering innovation as an internal activity of businesses supported by government technology plans and financial incentives. However, the landscape has transformed with globalization and heightened technological competition, expanding the system's scope to encompass the entire innovation ecosystem. This evolution emphasizes the importance of open, collaborative innovation, stressing cooperation and communication among all stakeholders

Keywords: National Innovation System, Innovation Ecosystem, Framework Construction, Innovation Collaboration, Innovation Policy

Introduction

This article aims to provide references and insights for the practical application of the national innovation system by analyzing its theoretical evolution and overall framework construction. The concept and practice of the national innovation system have evolved over time. Initially, innovation was seen as an internal activity of businesses, and the government supported it through technology plans and financial subsidies. However, with the intensification of globalization and technological competition, the scope of the national innovation system has expanded to the entire innovation ecosystem, emphasizing the openness and collaboration of innovation and advocating for cooperation and communication among all stakeholders.

The national innovation system's framework aims to coordinate and integrate innovation elements, including enterprises, higher education institutions, and research organizations. It utilizes various mechanisms and policies to encourage and support innovation. Both theory and practice have shown that a sound framework for the national innovation system can provide favorable conditions for innovation activities, driving the enhancement of innovation capabilities and the conversion of innovative outcomes.

This study adopts a literature review approach, theoretical analysis method, and comparative method to conduct an in-depth investigation of the national innovation system, resulting in a relatively comprehensive theoretical framework. By organizing the historical evolution of the national innovation system, we gain a better understanding of its developmental trajectory and patterns, providing valuable references for future national innovation system construction. Additionally, optimizing and improving the structure of the national innovation system enhances its effectiveness and adaptability in practical applications. The innovation of this research lies

in systematically organizing the historical process of the development and evolution of the national innovation system, as well as improving its structural framework. Based on a comprehensive analysis of the theories of the national innovation system, this study draws several significant conclusions. The developmental process of the national innovation system is complex and diverse, requiring a comprehensive consideration of historical backgrounds and national characteristics. Through reviewing and summarizing the historical development of the national innovation system, we identify successful experiences and lessons, which hold crucial guiding significance for future innovation system construction.

1. Literature Review

The study of national innovation systems emerged in the mid-1980s, coinciding with the rapid globalization and informatization of the era. Since then, numerous researchers have analyzed the concept from diverse perspectives and approaches. Scholars such as C.Freeman, R.Nelson, and B-A.Lundvall is a representative figure in the study of the national innovation system. In C.Freeman's book "Technology Policy and Economic Performance: Lessons from Japan," C. Freeman argues that the national innovation system is a network constructed jointly by the public and private sectors, where the initiation, introduction, improvement, and dissemination of all new technologies are realized through the activities and interactions of its constituent parts [1]. C.Freeman analyzes the reasons for Japan's rapid economic growth using the framework of the national innovation system, opening up a new line of thinking for the study of economic growth. In R.Nelson's book "National Innovation Systems: A Comparative Analysis," R.Nelson researches the national innovation systems of 14 countries. R.Nelson points out that these modern national innovation systems are institutionally complex. They encompass various institutional factors and technological behavior factors. These factors include universities that are dedicated to providing public technical knowledge, as well as institutions such as government funds and planning[2]. R.Nelson argues that profit-driven enterprises are the core of all these innovation systems, competing and cooperating. B-A.Lundvall focuses on analyzing the micro foundations of the national innovation system, emphasizing the role of "ultimate users" such as workers, consumers, and the public sector in innovation, and provides a preliminary analysis of the construction of a national innovation system model[3]. P.Patel and K.Pavitt argue that different countries' technology investment policies result in widening technological gaps between nations. The theoretical framework of the national innovation system can help countries determine how to invest in technology and understand the differences in investment effects among different countries[4]. American scholars R.Nelson and S.Winter delve into the evolution and influencing factors of the national innovation system in their co-authored book "An Evolutionary Theory of Economic Change." They explore the relationship between innovation and economic growth and the impact of policies on the development of the innovation system[5]. British scholar B.Metcalfe focuses on knowledge and technology exchange within the national innovation system, emphasizing the importance of knowledge flow and technological evolution for innovation capability, and introduces the concept of knowledge exchange networks[6]. M.Marcal explores the formation and evolution process of the national innovation system, emphasizing the influence of technology and industrial policies on the development of innovation systems and proposing the concept of "innovation policy networks"[7]. C.Edquist emphasizes the importance of institutional factors in the study of the national innovation system and introduces the concept of "innovation policy," discussing the role of government and policy tools in the innovation process[8].

The contributions of these researchers have greatly advanced the study of national innovation systems, providing crucial theoretical support for formulating innovation policies and promoting economic development. Through in-depth research on national innovation systems, people can gain a better understanding of the differences in innovation and technological development among different countries, thereby offering targeted policy recommendations for national innovation and development.

2. Methodology

In the first stage, the theoretical evolution of the national innovation system is investigated using a literature review method. Relevant literature and research findings are collected to organize and analyze the concept, connotation, and evolutionary process of the national innovation system. By sorting out the views and theories of early scholars and researchers, a basic understanding of the national innovation system is established, and the focus and direction of the research are clarified.

The second stage of the research involves a case study method to analyze the national innovation system of countries like the United States, Germany, Sweden, and China. Through these case studies, the research aims to gain insights into the strategies, organizational structures, and policy measures employed by different nations to build their national innovation systems. The ultimate goal is to understand the impact of these approaches on innovation capabilities and economic development.

The third stage of the research involves a comparative analysis of the national innovation system types of different countries, with a focus on identifying their strengths, weaknesses, and characteristics. This will help reveal a broader range of national innovation system models. Two main types are placed in the comparative study: the structure of "interconnected subjects mode" national innovation system and the structure of "independent subjects mode" national innovation system.

3. Research Results

4.1 The Theory of National Innovation System

The theoretical origins of the national innovation system can be traced back to the book "The National System of Political Economy," published by the German economist F.List in 1841. In this work, he introduced the concept of the "national system" and analyzed how "national characteristics" influence a country's economic growth performance and the technological choices of latecomer nations. F. List's book provided a conceptual framework for developing later theories on national innovation systems[9].

C.Freeman (1987) categorized the concept of the national innovation system into two broad and narrow definitions. The broad definition includes all institutions within the national economic system involved in introducing and diffusing new products. The narrow definition of the national innovation system encompasses institutions directly related to technological activities and supporting systems such as education and technology nurturing systems[10]. C.Freeman's theory of the national innovation system focuses on analyzing the relationship between technological innovation and national economic development (as shown in Figure 1). His model particularly emphasizes the impact of national

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characteristics on economic development.

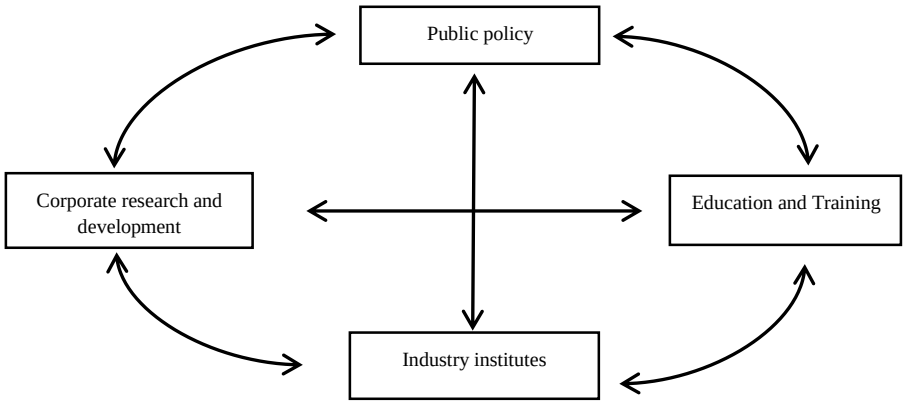

Figure 1: The structure of the national innovation system according to C.Freeman's theory

R.Nelson and E.Rosenberg, in their collaborative work "National Innovation Systems," published in 1992, proposed a theoretical framework and model for the national innovation system. According to their theory, the national innovation system is a complex technological innovation system composed of various institutions and organizations. It is a complete, coordinated, and interactive system comprised of different types of organizations, institutions, and individuals. These organizations, institutions, and individuals are interconnected and coordinated through various channels and means, working together to promote the development of technological innovation. These organizations and institutions include government departments, universities, research institutions, businesses, and other non-governmental organizations. According to R.Nelson and E.Rosenberg's theory, the national innovation system consists of three primary levels: infrastructure level, institutional arrangements level, and technological innovation level (as shown in Figure 2). Infrastructure includes physical and non-physical facilities, such as energy, transportation, communication, education, research, and intellectual property protection. The institutional arrangements level refers to various regulations, policies, and systems established by the government, including intellectual property protection systems, research and development investment systems, tax systems, and more. The technological innovation level encompasses various activities, including research and development, technology transfer, technology application, etc.

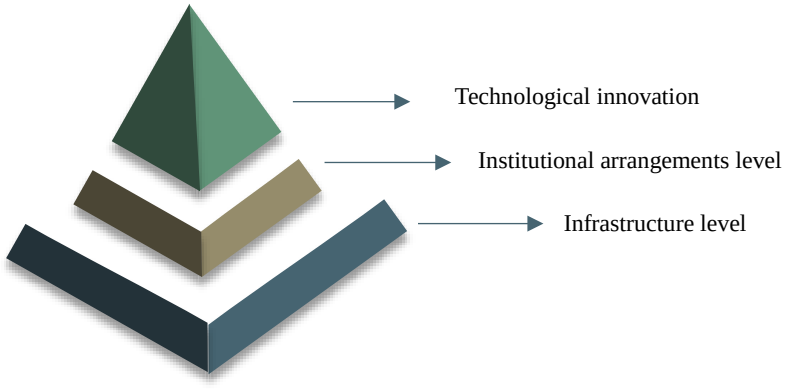

Figure 2: The structure of the national innovation system according to R.Nelson and E.Rosenberg's theory

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B-A.Lundvall initially studied the national innovation system from a micro perspective. In 1985, in his book "Product Innovation and User-Producer Interaction," B-A.Lundvall emphasized the importance of the relationship between firms and users as a crucial factor affecting national economic development. He identified cultural, geographical, and governmental factors as influential in shaping the interaction between firms and users. In 1992, in his book "National Innovation Systems: Towards a Theory of Innovation and Interactive Learning," B-A.Lundvall examined how national boundaries affect technological innovation performance. He highlighted that the efficiency of a national innovation system could be measured by the efficiency of producing, diffusing, and utilizing economically valuable knowledge. According to B-A.Lundvall, knowledge is the most critical resource in the modern economy, and learning is the crucial process for acquiring knowledge. He emphasized that learning is an interactive social process between individuals (as shown in Figure 3). Therefore, interactive learning is considered the core of the national innovation system, encompassing formal R&D systems, educational training, and learning embedded within economic activities[11].

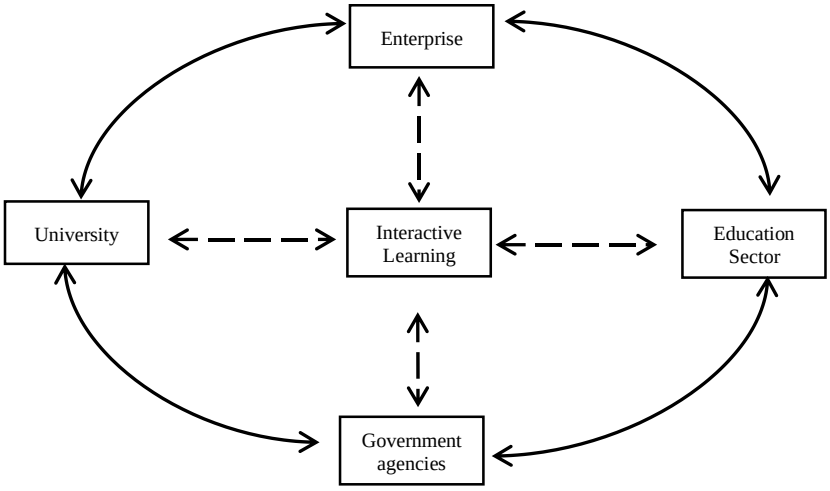

Figure 3: The structure of the national innovation system according to B-A.Lundvall's theory

P.Patel and K.Pavitt (1994) argue that the national innovation system is an organic combination of national institutions, incentive models, and competitiveness (as shown in Figure 4), which collectively determine the direction and speed of a country's learning of new knowledge and technologies[12]. The incentive model encourages innovation through various policies, institutions, and mechanisms. This includes protecting intellectual property rights, providing financial support, offering tax incentives, government procurement of innovative products, providing education and training, promoting collaboration and cooperation, and establishing fair evaluation and reward mechanisms to stimulate innovation. These factors work together to drive innovation activities. Technological investment is a significant contributor to the technological gap between nations. The theory of the national innovation system effectively addresses the challenge of how countries can engage in technological investment.

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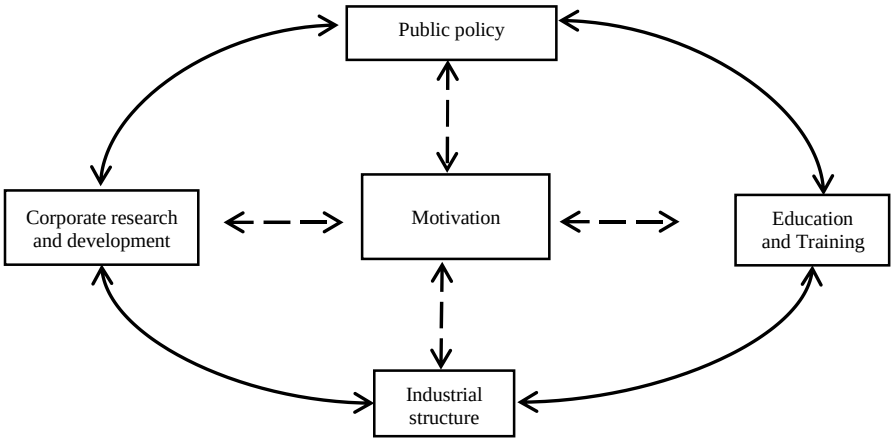

Figure 4: The structure of the national innovation system according to P.Patel and K.Pavitt's theory.

In conclusion, the national innovation system is a system at the national level that consists of enterprises, universities, research institutions, and other subjects. It is formed through their interactive actions towards a series of common social and economic goals. The main activities within this system include technology research and development, technology introduction, and technology diffusion. The various components of the system generate knowledge diffusion and technology transfer, establishing interactive mechanisms that enhance innovation performance and drive economic growth. Learning and motivation are indispensable elements within the national innovation system. Learning provides the source of knowledge and the foundation of capabilities, while motivation ignites the drive and enthusiasm of the innovative entities. Through effective learning and motivation mechanisms, a country can cultivate and attract outstanding innovative talents, promote technological progress and economic development, and achieve optimization and upgrading of the national innovation system.

4.2 The implement of National Innovation System

Based on the theoretical evolution of the national innovation system, it is possible to clarify the common structure of a national innovation system. However, the practical implementation of national innovation systems varies among different countries. In this analysis, we will examine the national innovation systems of four countries. The national innovation systems of four countries will be analyzed below.

The structure of the national innovation system in US is based on a triple helix structure that involves the government, industry, and academia. These subjects possess unique innovation chains and collaborate to foster national development. This organic and interactive network is the backbone of the US innovation system[13].

Enterprises in US are the most prominent investors of research activities. Enterprises establish dedicated research teams of scientists, engineers, and technical experts. These teams are committed to conducting fundamental research and exploring new scientific domains and technological frontiers in search of innovative solutions and business opportunities. The R&D teams of enterprises are responsible for the design, development, and testing of applied development projects. Simultaneously, they employ effective project management methods to ensure timely and high-quality completion. Enterprises have autonomy during the research and development phase, allowing them to independently design and implement innovative projects, actively exploring new technological directions and business opportunities.

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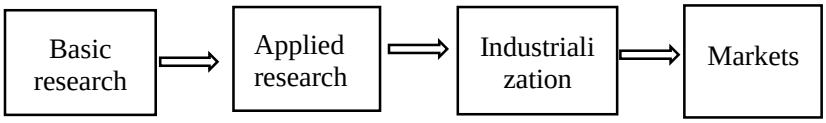

Figure 5: The innovation chain of the enterprises in US

Universities provide funding and resource support to teachers and researchers by establishing academic research projects and driving the advancement of fundamental research. Additionally, universities leverage channels such as science and technology parks to transform research outcomes into commercialized technologies. Through entrepreneurship and innovation centers, universities facilitate the transformation of research achievements into commercial subjects.

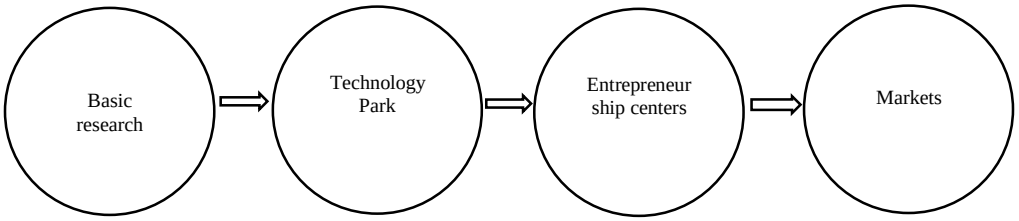

Figure 6: The university innovation chain in US

Scientific Research Institutions carry out fundamental research through internal research teams that are dedicated to exploring and innovating in cutting-edge technologies. The professionals within these institutions development deep into their respective fields, driving knowledge innovation and scientific support. These efforts attract attention and facilitate the application and commercialization of fundamental research achievements[14].

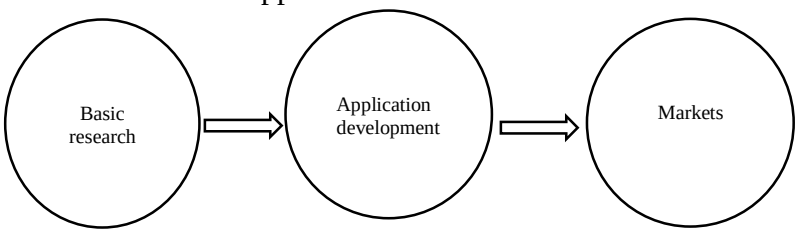

Figure 7: The innovation chain in scientific research institutes in US

The structure of the US innovation system consists of three main subjects. Enterprises occupy a central position in this system, with a complete innovation chain covering fundamental research, applied research, and industrialization. During the R&D phase, enterprises have autonomy and control, allowing them to independently design and implement innovative projects while actively exploring new technological directions and business opportunities. Universities can commercialize scientific and technological achievements through innovation, enabling them to transform research outcomes into tangible commercial subjects and promote the market application and commercial development of innovative outcomes. The role of the government in the U.S. innovation system is characterized by "weak intervention." This means that the government's intervention in innovation subjects is limited, ensuring the independence and autonomy of each innovation entity. This state of affairs allows for an efficient network system within the innovation system. The efficiency of this network system facilitates accelerating the translation and application of innovative outcomes, driving sustained economic growth and societal progress[15].

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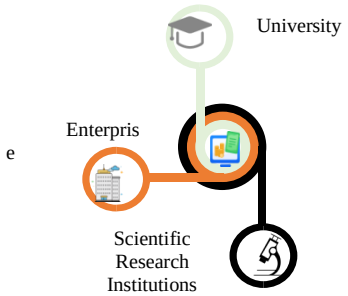

Figure 8: The structure of the national innovation system in US

Germany has built a comprehensive enterprise innovation chain characterized by its unique dual-center feature comprising both large and small enterprises. Large enterprises focus on technology development and industrialization. At the same time, numerous small and medium-sized enterprises leverage their innovative advantages in niche areas and form stable and complementary partnerships with large enterprises. German large-scale enterprises possess excellent engineering research and development teams and high-quality assurance systems and benefit from numerous specialized small and medium-sized enterprises that provide them with high-standard and high-quality component supplies[16]. Through the collaboration between large and scaled small enterprises, stable and complementary partnerships are formed, with small and medium-sized enterprises providing components. In contrast, large enterprises engage in technology development and industrialization. This ultimately allows products to enter the market, establishing a complete enterprise innovation chain and enhancing the overall efficiency of the innovation system.

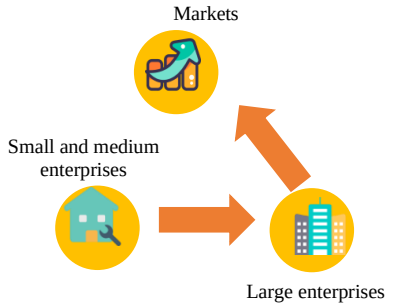

Figure 9: Enterprise Innovation Chain in German

German scientific research institutions have established a complete innovation industry chain to ensure the adequate flow of innovation outcomes into the market. The Max Planck Society is a research institution that focuses on fundamental research, primarily addressing common scientific problems. Society's research is centered around the fundamental knowledge of various disciplines, driving scientific development and theoretical innovation. The Max Planck Society is dedicated to fundamental research and primarily focuses on solving common scientific problems[17]. On the other hand, the Fraunhofer Society is dedicated to applied research, focusing on transforming research outcomes into practical applications and promoting the commercialization of innovative results. The Society emphasizes the application of scientific and technological achievements in industries and markets, contributing to socio-economic development through technological innovation[18]. The Helmholtz Association, on the other hand, specializes in forward-looking high-tech research, covering areas such as space, environment, energy, and health. The association's research aims to advance science and technology and

provide valuable scientific support for social and economic development. Through these efforts, German research institutions are committed to translating innovative outcomes into practical applications and facilitating their successful entry into the market.

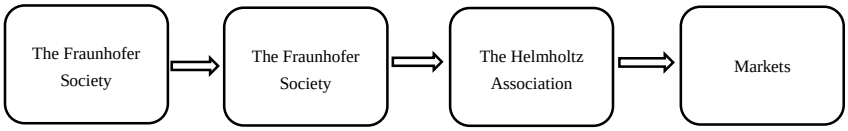

Figure 10: The Innovation Chain of scientific Research Institutes in German

The universities in German are dedicated to translating innovative outcomes from the stage of fundamental research into practical products and services. Universities actively promote technology transfer and intellectual property protection. They encourage faculty members and researchers to commercialize their findings by providing professional support and legal consultation to protect intellectual property rights. Universities are committed to supporting entrepreneurial activities and providing resources and support for entrepreneurs. They establish entrepreneurship centers and incubators that offer support services such as entrepreneurship training, mentorship guidance, and office spaces, helping entrepreneurs bring innovative products to the market.

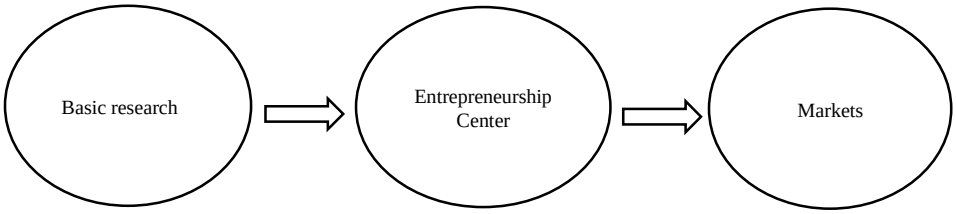

Figure 11: The innovation chain of university in German

In general, the structure of national innovation system in German includes the dual-center feature of enterprises, a complete enterprise innovation chain, the innovation industry chain of research institutions, and the support for basic research and entrepreneurship by universities. These characteristics work harmoniously to enhance Germany's innovation capacity and economic development.

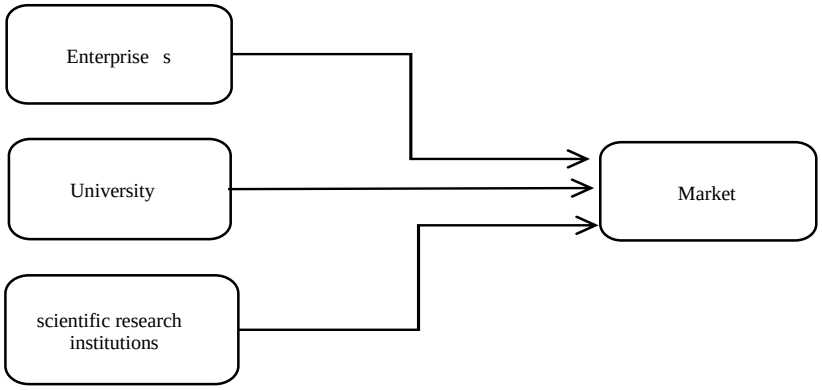

Figure 12: The structure of Germany's National Innovation System

The biggest characteristic of Sweden's innovation system is the clear division of labor and efficient collaboration among universities, industries, and the government (as shown in Figure 13).

The structure of national innovation system in Sweden is primarily composed of three main subject universities, businesses, and public research institutions. They are interconnected through a tightly integrated innovation chain, working together to drive technological innovation and industrial development[19].

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Universities is known as knowledge creation and talent development drivers. Universities generate new knowledge and technologies through fundamental and applied research, injecting vitality into the innovation chain. Additionally, universities are responsible for nurturing highly skilled individuals, equipping them with innovative capabilities, and supplying them to businesses and research institutions. This further facilitates the continuity of the innovation chain.

Scientific research institutions in Sweden play a complementary and supportive role in Sweden's innovation system. Scientific research institutions in Sweden possess specialized knowledge and technical capabilities in specific domains. Research institutions collaborate closely with universities and businesses, providing professional support and technical services. This strengthens the linkage and coordination of the innovation chain, further promoting technological innovation and industrial development.

Enterprises in Sweden are essential participants and drivers of innovation activities in Sweden's innovation system. While enterprises are relatively more focused on technology research related to product development compared to universities, they recognize the importance of basic research for innovation. Therefore, enterprises in Sweden actively collaborate with universities, sharing knowledge and resources, providing financial support to universities, and retaining ownership of the resulting patents [20]. This close collaboration forms a vital link in the innovation chain, facilitating the transformation and application of technological advancements. Through enhanced communication and cooperation, the collaboration between enterprises and universities effectively combines primary research outcomes with market demands. Enterprises can translate scientific research findings into innovative products or solutions and bring them to the market. This seamless connection and interaction in the innovation chain drive the commercialization of technological achievements, making significant contributions to economic development and social progress.

In conclusion, the national innovation system in Sweden is characterized by the interconnection and close collaboration among universities, companies, and research institutions. They play distinct roles and responsibilities, forming a cohesive and interactive relationship. Through the linkage and coordination of the innovation chain, they collectively contribute to the country's continuous development (as shown in Figure 13).

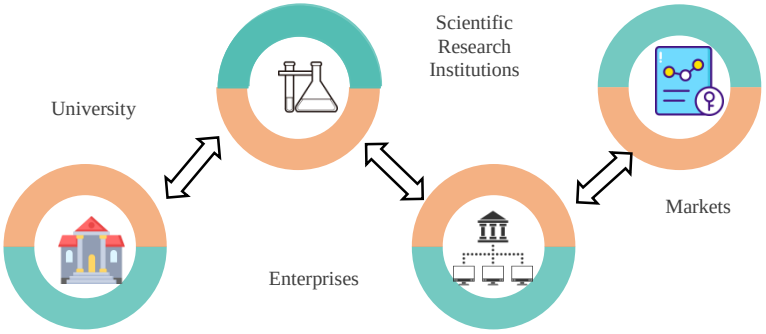

Figure 13: The structure of Sweden's National Innovation System

The basic framework of China's national innovation system includes integrating industry, academia, and research, aggregating innovative resources, and open collaboration [21]. This system emphasizes comprehensive and systematic construction, balanced and coordinated development, market orientation and application orientation, and long-term sustainability and stability assurance.

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As the main driving force of economic activities, enterprises actively participate in the innovation system by providing practical problems and market demands, guiding universities' research directions and objectives[22]. As creators and disseminators of knowledge, universities provide scientific support and highly skilled professionals to enterprises. Through knowledge innovation and talent development, universities contribute to businesses' scientific support and human resource needs. Scientific research institutions play a bridging role between universities and enterprises[23]. They provide support and resources for the university's primary research and exploration of cutting-edge technologies, facilitating the transformation and application of innovative outcomes. The close collaboration among enterprises, universities, and research institutions forms a solid foundation for innovation, driving China's continuous development and progress in scientific and technological innovation (as shown in Figure 14).

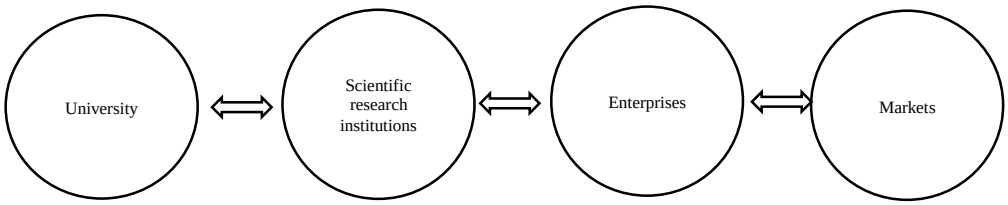

Figure 14: The structure of the National Innovation System in China

4.3 The types of the National Innovation System

Based on the theoretical development of a national innovation system and the analysis of different national innovation system structures , the structure of a national innovation system is not simply the accumulation of individual elements, and the academia-industry-research system alone cannot fully demonstrate the intrinsic logic of an innovation system[24]. The framework of a national innovation system structure exhibits diverse characteristics that vary from country to country, and even within the same country, the system structure may change over time[25]. However, overall, the structure of a national innovation system still exhibits certain regularities. Based on the different functional positioning of subjects and modes of the division of labor and collaboration, this paper classifies the innovation system into two different structure types: "interconnected subjects mode" and "independent subjects mode."

The "interconnected subjects mode" innovation system structure consists of universities (with a focus on basic research), research institutions (with a focus on applied research), and enterprises (with a focus on industrialization), emphasizing the division of labor and collaboration among different subjects (as shown in Figure 15). In this structure, the subjects refer to the three major innovation subject universities, research institutions, and enterprises. Interconnected collaboration refers to the clear division of labor and collaboration among these subjects. The three subjects focus on different stages of research, with universities focusing on basic research, research institutions focusing on applied research, and enterprises focusing on industrialization[26]. All three subjects are indispensable, as they form an integrated industrial chain and are necessary for completing the innovation process.

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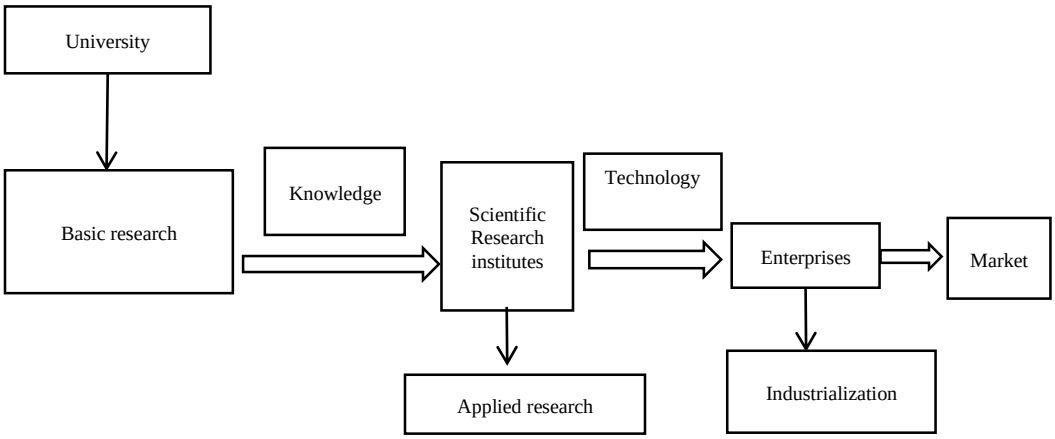

Figure 15: The structure of "interconnected subjects mode" national innovation system

In many developed countries, there is not always a clear division of labor and collaboration among the three major innovation subject universities, research institutions, and enterprises[27]. Instead, they maintain a certain level of independence. Initially, the design of the innovation system emphasized the "interconnected subjects mode" structure. The functions of the three major innovation subjects have become increasingly blurred. For example, universities establish campus enterprises based on research achievements.This indicates that enterprises, scientific research institutions, and universities can form an independent innovation chain through their own basic research and application development[28], and jointly explore market opportunities, thereby promoting the enhancement of national innovation capabilities. (As shown in Figure 16), in the "independent subjects mode" structure, the term "subjects" refers to the three primary subjects, "independent" implies that each entity has its own independent and complete innovation chain in parallel, and "mode" implies that the innovation chains of the three subjects are not entirely disconnected but interact through elements such as technology, talent, and funding[29].

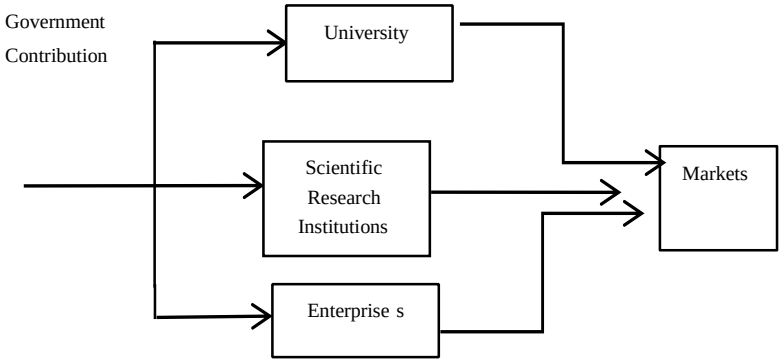

Figure 1 6: The structure of "independent subjects mode" national innovation system

5. Discussion

Over the past few decades, scholars have extensively researched and discussed the theoretical evolution and overall types of national innovation systems. Initially, the focus was primarily on the organization and management of scientific research and technological development within these systems. However, over time, scholars recognized that innovation is a complex process that involves collaboration among multiple domains and stakeholders. Scholars gradually realized that constructing a national innovation system goes beyond the

collaboration between research institutions and businesses. It also requires the involvement of government, higher education institutions, financial institutions, and various sectors of society. This understanding transformed the national innovation system from a linear model to a more complex network model, where the various components are interconnected and mutually influencing each other.

Our research innovation lies in the analysis of the innovation system types of four countries, leading us to identify two types of national innovation system types. This innovative perspective allows us to better understand the characteristics, advantages, and challenges of different national innovation systems. Furthermore, it enables us to propose relevant policy recommendations and strategic directions. Our findings offer a new perspective and insights for the research and practice of national innovation systems.

Choosing the appropriate innovation system structure requires considering factors such as the country's development needs, industry characteristics, resource allocation, and innovation capabilities. In practice, it is possible to utilize different innovation system types based on specific circumstances and the requirements of different fields. Continuous exploration and innovation in the design and optimization of innovation systems can be undertaken to drive national innovation and economic development. However, the article still has limitations: It mainly focuses on developed countries and regions, such as the United States and Germany, with a comparative study based on China's practice. In future research, more samples from different countries and regions, especially developing countries, could be collected to validate and expand the research findings of this article. The "interconnected mode" and "independent mode" are two ideal operating modes, but some countries may have a combination of both structures rather than a binary relationship. Therefore, future discussions will focus on diversifying innovation system structures in such cases.

6. Conclusion

Through our analysis of the national innovation system, we have demonstrated that innovation is the core driver of economic growth and social progress. By analyzing and identifying the multidimensional characteristics of the national innovation system, as well as the synergistic interactions among its various components, we have provided clear guidance and a roadmap for its construction. The theoretical significance of the national innovation system lies in deepening understanding of innovation, revealing its patterns and mechanisms, and providing new perspectives and approaches for the development of innovation theory. In practice, the establishment of a national innovation system holds great importance in promoting technological advancement, economic growth, and social progress. It provides comprehensive support and assurance for innovation activities, enhancing a nation's innovative capacity and overall competitiveness. The ultimate goal of the national innovation system is to achieve a virtuous cycle of technological innovation and socio-economic development, propelling a nation towards becoming a leading force in technology and an innovative nation.

In conclusion, the analysis of the theoretical evolution and overall framework of the national innovation system has demonstrated the significance of innovation for national development and determined the pathway to constructing a synergistic and efficient innovation system. It holds both theoretical and practical importance. Through the establishment of a national innovation system, a country can enhance its innovative capacity, drive technological progress and economic growth, elevate its position and influence in the global innovation landscape, and achieve sustainable development.

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