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Coupling Coordination Degree of Government Support, Financial Support and Innovation and Its Impact on Economic Development

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ABSTRACT This paper reveals the coupling mechanism of government support, financial support, and innovation. Using panel data from 28 provinces in China from 2007 to 2016 as a research sample, the coupling coordination degree model is used to measure the coupling coordination degree of government support, financial support, and innovation, and the empirical analysis of its relationship with economic development is conducted through projection pursuit model, static panel data model and dynamic panel data model. The main results show that: (1) The coupling coordination degree of government support, financial support, and innovation in the eastern, central, and western region is on the rise, but there are large differences between regions. (2) The coupling coordination degree of government support, financial support, and innovation has a significant positive impact on economic development, and there are regional differences in its role in promoting economic development. That is, the coupling coordination degree of government support, financial support, and innovation has significantly promoted the economic development of the eastern region, but has no significant impact on the economic development of the central and western region.

INDEX TERMS Government support, financial support, innovation, coupling coordination degree, economic development.

I. INTRODUCTION

Since the outbreak of the financial crisis in 2008, the negative effects of economic globalization have been prominent, and global economic growth has been sluggish. Both theory and practice have proved that innovation is the meta motive force for the long-term stable growth of the economy [1]. For this reason, how to realize the innovation-driven development strategy has become the focus of attention of all countries. Finance is critical to innovation [2]. The long process of innovation, from research and development to achievement transformation, to technology industrialization, requires the support of financial capital [3]. However, innovation activities are characterized by high costs, large risks, strong spillover, and information asymmetric. The profit-seeking and speculative nature of financial capital makes it insufficient for the initial funding of innovation, which can easily lead to market failure of innovative production [4]. This provides a theoretical basis for government intervention in the field of innovation. Giving full play to the support role of the government is an important measure for many countries to promote the development of innovation [5]. On the one hand, the government can provide funding support to reduce the risks and costs of innovation entities, and encourage them to engage in innovation activities. On the other hand, by setting up an innovation platform, the government reduces the time and cost for innovation entities to find effective knowledge and cultivate professional skills, and improves the efficiency of innovation. Government support, financial support, and innovation are mutually influential and indivisible. Achieving a healthy coupling coordination relationship between the three will help promote economic development, and vice versa, it is not conducive to economic development. Therefore, how to realize the coupling coordination of government support, financial support, and innovation, and realize innovation-driven development strategy, thereby helping the economy get out of the current predicament and achieve sustainable and healthy development, has become an urgently discussed topic.

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At present, the research on government support and innovation is mainly focused on the following two aspects. First, explore the necessity of government support for innovation. Freeman believes that basic research should be funded by state funding. If the state stops funding for scientific research, the consequences are unthinkable, and private investment cannot make up for the gap left by state funding [6]. Mazzucato [7], Zhang and Du [8] and Wang *et al.* [9] explained the reasons for government access to the field of innovation from the perspectives of risk, publicity, spillover and information asymmetry of innovation. Second, explore the effect of government support on innovation. Szucs pointed out that R&D subsidies have a positive impact on enterprise innovation. For each increase in standard deviation R&D subsidies, patents increase by 41%, total citation times increase by 22%, and average citation times increase by 13% [10]. Jiang used the data of new energy automobile industry in China for empirical research and found that there was a positive correlation between government subsidies and enterprise R&D investment, and with the increase of government subsidies, its promoting effect on enterprise R&D investment gradually weakened [11]. Du conducted an empirical study on the data of new energy enterprises in China, and found that enterprises engaged in innovation activities would enhance their innovation capacity and investment after receiving government support, thus leading to the improvement of enterprise innovation performance [12]. With the deepening of research, some scholars have studied the impact of government subsidies on innovation under different enterprise sizes. Bronzini conducted an empirical analysis using the data of enterprises in northern Italy and found that R&D subsidy has a significant positive impact on the number of patent applications of both small and large enterprises, and has a greater impact on small enterprises [13].

The relationship between finance and innovation has received close attention from scholars, and the research results are relatively rich. Some scholars have conducted research on the impact of the development of capital market, venture capital and bank credit on innovation. Cai conducted an empirical analysis using the data of listed companies, and found that the more developed the capital market is, the greater the promotion effect of innovation [14]. Rudra took 19 European economic area countries as research objects to explore the relationship between venture capital and innovation. The empirical results showed that venture capital plays an important role in promoting the development of innovation in most countries [15]. Meierrieks pointed out that transaction costs caused by market imperfections would limit investment in innovative projects, while financial intermediaries could reduce these transaction costs. At the same time, empirical analysis using transnational data found that private credit had a significant positive impact on innovation output. Taking into account the banking crisis, private credit still has a significant positive impact on innovation output [16]. In addition, some scholars believe that the dynamic flow of financial factors makes finance have obvious linkage characteristics between regions. Therefore, it is necessary to consider financial development and spatial associations in a unified way, so as to more fully explain the inherent mechanism of financial influence on innovation [17]. Both Gao *et al.* [18] and Cao and Zhang [19] have found through research that the financial development of neighboring areas has a positive impact on local innovation. With the deepening of research, some scholars have studied the difference in the effect of finance on innovation under different levels of economic development and financial development. Zheng and Zheng found that when economic development is at a low level, finance has a negative impact on innovation and when economic development reaches a certain level, finance has a positive impact on innovation [20]. Li *et al.*pointed out that the higher the financial maturity, the stronger the role of finance in promoting corporate innovation [21].

By sorting out relevant literature, it can be known that the research on the effect of government support and financial support on innovation has achieved relatively rich research results, which provides a certain guiding significance for the development of innovation, but existing research still has certain limitations and shortcomings. First, a healthy coupling coordination relationship between government support, financial support, and innovation can effectively promote economic development. However, most studies have ignored the coupling coordination relationship between the three. Second, there are few literatures that measure the coupling coordination degree of government support, financial support, and innovation, and there is a lack of research on its impact on economic development. Thirdly, the existing researches mostly use a single indicator such as GDP or per capita GDP as a substitute variable for economic development, which is largely unable to accurately assess the status of economic development. Based on this, this paper reveals the coupling mechanism of government support, financial support, and innovation. Using panel data from 28 provinces in China from 2007 to 2016 as a research sample, the coupling coordination degree model is used to measure the coupling coordination of government support, financial support, and innovation, and the empirical analysis of its relationship with economic development is conducted through projection pursuit model, static panel data model and dynamic panel data model. It is expected to provide a meaningful reference for grasping the evolutionary trend of government support, financial support, and innovation, realizing an innovation-driven development strategy, and ensuring long-term stable economic growth. The research framework is shown in FIGURE 1.

II. COUPLING MECHANISM

The meaning of coupling refers to the phenomenon that two or more systems or forms of motion affect each other through interaction [22], which originated in physics and was later applied to the social sciences such as national economic operation and management [23]. The basic premise of coupling is that some relationship exists between the coupling

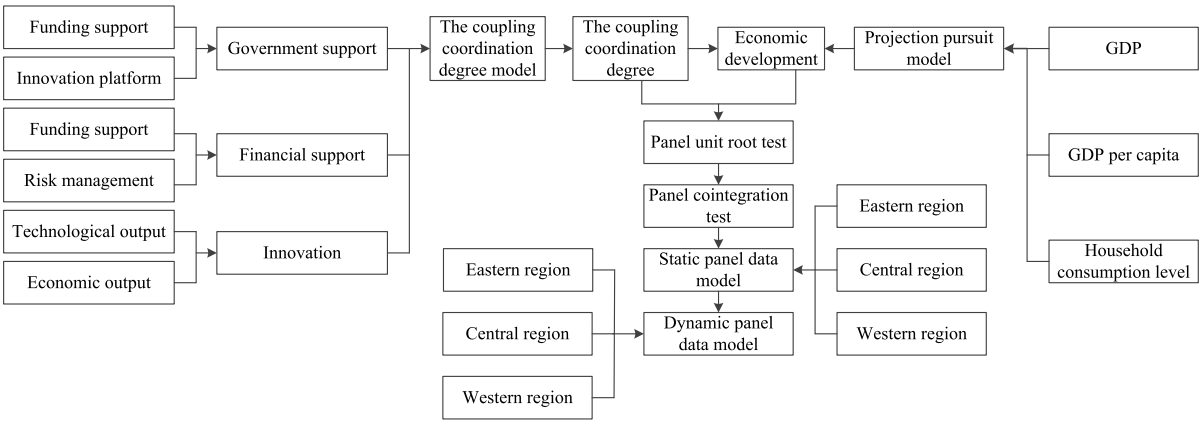

FIGURE 1. Research framework.

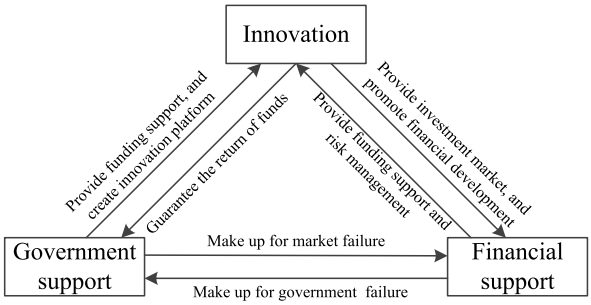

FIGURE 2. Interaction between government support, financial support and innovation.

elements, and the result of coupling is that the properties of the coupling elements are enlarged or reduced [24]. In a composite system consisting of government support, financial support, and innovation, there is a complex nonlinear interaction between the three (as shown in FIGURE 2).

Firstly, the coupling of government support and financial support is manifested by the two exerting their respective advantages and strengths, overcoming their respective limitations, and improving their operating efficiency in the process of interaction [25]. Innovation activities are characterized by high risks and strong spillover. The innovation support behavior of financial entities based on the consideration of risk and their own profit-making motives will lead to insufficient funding support in the initial stage of innovation, and then cause market failure and market shortage. Government departments can compensate for market failure by providing funding and policy support to ensure the initial growth of innovation projects [26]. With the continuous advancement of the innovation project process, the funding requirements have grown exponentially. At this time, the support of financial entities with large capital resources is needed to make up for the instability and limitation of government support [27]. At the same time, financial entities have the vast majority of market information, which can solve the problem that government departments cannot achieve optimal policy support due to the inherent weakness in judging market information [28]. In addition, financial institutions can improve the problem of inefficient resource allocation caused by the lack of incentive and constraint mechanisms for government departments through prior inspection and process supervision of innovation activities.

Secondly, government departments promote the development of innovation by providing funding support and creating innovation platforms, and the development of innovation can ensure the sustainability of government support. Government departments fund innovation activities through direct R&D subsidies, which can make up for the funding gap caused by market failure in innovation activities. This provides sufficient funding support for innovation activities, encourages innovation entities to carry out innovation activities, which is conducive to the development of innovation [29]. At the same time, the created innovation platform can provide specialized services such as knowledge acquisition, technology diffusion, achievement transfer and management consulting for innovation entities, reduce the time and cost for innovation entities to find effective knowledge and develop professional skills, so as to improve the efficiency of innovation [30]. The development of innovation requires the support of government departments, and it also brings certain social benefits and economic benefits to the input of government departments. The improvement of innovation has promoted the growth of the knowledge economy and the increase in national income, which has brought more tax revenue to government departments. The government departments have realized capital return and ensured the sustainability of government support [31].

Thirdly, finance can provide funds support and risk management for innovation activities, and innovation can promote the development of finance. Finance can provide equity and debt financing for innovation activities, meet the increasingly enlarged capital needs in the three stages of innovation, effectively ease the financing constraints of innovation entities, and encourage them to enter the field of innovation [32]. At the same time, scientific and technological insurance can effectively disperse and resolve the high risks faced by

innovation entities, ensure the continuity and integrity of innovation activities, enhance the willingness of innovation entities to innovate, so as to promote the development of innovation [33]. The development of innovation requires financial support, and it also brings certain social benefits and economic benefits to financial capital. Innovation activities provide investment markets for financial entities. Financial entities have obtained high investment returns while taking high risks, and realized the expansion of financial capital scale [31]. At the same time, the financial innovation brought by innovation can effectively reduce financial transaction costs, improve financial service efficiency, expand financial service boundaries, and promote financial development [34].

It can be seen that government support, financial support, and innovation achieve a spiral rise through the healthy coupling coordination of each other, so that the composite system composed of them evolves to a higher level, thereby promoting economic development. On the contrary, under the state of unhealthy coupling coordination of government support, financial support and innovation, government support and financial support cannot complement each other, which will affect the efficiency of resource allocation of each other and will not be conducive to the promotion of innovation. Decrease in innovation output will reduce the investment income of the financial entities, and then cause capital outflows, leading to the shrinking of the financial capital. It also will reduce the performance of government support and slow the return of fiscal funds, thereby restrict the sustainability of government support. Such a reciprocation between government support, financial support and innovation will form a vicious circle, degrading the composite system to a lower level, which is not conducive to economic development.

III. RESEARCH METHODS

A. THE COUPLING COORDINATION DEGREE MODEL

The coupling coordination degree model applied in this paper is mainly derived from the research results of Xu *et al.* [35], which has been favored in the research on coupling coordination theory in recent years. The calculation steps of the coupling coordination degree model are as follows.

(1) Data standardization. In order to eliminate dimension and make the data comparable, this paper standardized the initial data. In this paper, let G_{ijnt} represents the j-th second-level indicator of i-th first-level indicator in the government support system in the n-th region at time t, the corresponding value is x_{ijnt} ($i = 1, 2, \cdots, i'$, $j = 1, 2, \cdots, j'$, $n = 1, 2, \cdots, n'$, $t = 1, 2, \cdots, t'$), i' is the number of the first-level indicator of the government support system, j' is the number of the second-level indicator under the i-th first-level indicator, n' is 28, t' is 10. Similarly, F_{ijnt} represents the j-th second-level indicator of i-th first-level indicator in the financial support system in the n-th region at time t, and its corresponding value is y_{ijnt}. I_{ijnt} represents the j-th second-level indicator of i-th first-level indicator in the innovation system in the n-th region at time t, and its corresponding value is z_{ijnt}. The standardized form is:

$$X_{ijnt} = \frac{x_{ijnt} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} \tag{1}$$

$$Y_{ijnt} = \frac{y_{ijnt} - \min y_{ij}}{\max y_{ij} - \min y_{ij}} \tag{2}$$

$$Z_{ijnt} = \frac{z_{ijnt} - \min z_{ij}}{\max z_{ij} - \min z_{ij}} \tag{3}$$

After the standardized treatment, the value range of the variable is [0,1]. In order to ensure that the value of the variable is greater than zero, this paper reference the treatment method of Zhou and Sheng [36] and replaces zero with one-tenth of the second smallest value of the variable.

(2) Determine the weight of indicators. The entropy method is objective in determining the weight coefficient, and the evaluation process is transparent and reproducible. Therefore, the entropy method is used to determine the weight of indicators. Taking the government support system as an example, the specific operation steps are as follows.

First, calculate the characteristic proportion of the second-level indicators.

$$h_{ijnt} = \frac{X_{ijnt}}{\sum_{n=1}^{n'} X_{ijnt}} \tag{4}$$

Second, calculate the entropy value of the second-level indicators.

$$e_{ijt} = -k \sum_{n=1}^{n'} h_{ijnt} \ln\left(h_{ijnt}\right) \tag{5}$$

where $e_{ijt} > 0$, $k = \frac{1}{\ln(n')}$.

Third, calculate the utility value of the second-level indicators.

$$g_{ijt} = 1 - e_{ijt} \tag{6}$$

Fourth, calculate the weight of second-level indicators.

$$w_{ijt} = \frac{g_{ijt}}{\sum_{j=1}^{j'} g_{ijt}} \tag{7}$$

Fifth, calculate the utility value of the first-level indicators.

$$g_{it} = \sum_{j=1}^{j'} g_{ijt} \tag{8}$$

Sixth, calculate the weight of first-level indicators.

$$w_{it} = \frac{g_{it}}{\sum_{i=1}^{i'} g_{it}} \tag{9}$$

Similarly, the weight of indicators of the financial support system and the innovation system can be obtained.

(3) Determine the comprehensive evaluation index of the system. The comprehensive evaluation index is a comprehensive consideration of the development status of various

indicators in the system, which is used to show the development trend of the system, and is the basis of calculating the coupling coordination degree. In this paper, the linear weighting method is used to calculate the comprehensive evaluation index of the system. Take the government support system as an example, the comprehensive evaluation index of its first-level indicator is:

$$X_{int} = \sum_{j=1}^{j'} X_{ijnt} \times w_{ijt} \tag{10}$$

The comprehensive evaluation index of the government support system is:

$$X_{nt} = \sum_{i=1}^{i'} X_{int} \times w_{it} \tag{11}$$

In the same way, the comprehensive evaluation index of the financial support system (Y_{nt}) and the innovation system (Z_{nt}) can be obtained.

(4) Calculate the coupling coordination degree. The coupling degree of government support, financial support and innovation is:

$$C_{nt} = \frac{3\left(X_{nt} \times Y_{nt} + X_{nt} \times Z_{nt} + Y_{nt} \times Z_{nt}\right)}{\left(X_{nt} + Y_{nt} + Z_{nt}\right)^2} \tag{12}$$

The coupling degree is of great significance for judging the strength of coupling between systems. However, simply using the coupling degree cannot identify the overall efficacy and synergy of the system. In particular, when the development level of each system is low and similar, using the coupling degree model will result in false evaluation results with a high degree of coupling of the total system, which is misleading. Therefore, the development level of the total system should be included to construct the coupling coordination degree model, in this way, the model can avoid wrong evaluation results. The development degree of government support, financial support and innovation is as follows.

$$T_{nt} = \alpha X_{nt} + \beta Y_{nt} + \gamma Z_{nt} \tag{13}$$

Among them, α, β, and γ represent the weight of the government support system, the financial support system, and the innovation system, respectively. This article considers the three to be equally important, so $\alpha = \beta = \gamma = 1/3$. The coupling coordination degree of government support, financial support, and innovation (hereinafter referred to as the coupling coordination degree) is:

$$D_{nt} = \sqrt{C_{nt} \times T_{nt}} \tag{14}$$

(5) Classification of the coupling coordination degree. Based on the classification of the coupling coordination degree by Yao *et al.* [37], this paper divides the coupling coordination degree into ten grades and three level (as shown in TABLE 1).

TABLE 1. The classification of the coupling coordination degree.

Category	Coupling Coordination Degree	Subclass
Disorder (Zone of unacceptable)	0.00-0.09	Extreme disorder
	0.10-0.19	Serious disorder
	0.20-0.29	Moderate disorder
	0.30-0.39	Light disorder
Transition (Zone of reluctantly accept)	0.40-0.49	Near disorder
	0.50-0.59	Reluctance coordination
Coordination (Zone of tolerance)	0.60-0.69	Primary coordination
	0.70-0.79	Middle coordination
	0.80-0.89	Well coordination
	0.90-1.00	High coordination

B. PROJECTION PURSUIT MODEL BASED ON REAL-CODED ACCELERATING GENETIC ALGORITHM

Compared with a single indicator, the use of comprehensive indicators can more comprehensively measure the research variables, which also leads to the problem of dimensionality reduction of high-dimensional data. Projection pursuit method is an emerging statistical method, which can project high-dimensional data to low-dimensional subspace, find projections that can reflect the structure and features of the original high-dimensional data, and achieve the purpose of reducing the dimensionality of high-dimensional data. This method has the advantages of good robustness, high accuracy and strong anti-interference [38].

The steps of the projection pursuit model are as follows.

First, data normalization. Let the data sample set be $\{x^*(i, j)|i = 1, 2, \cdots, n; j = 1, 2, \cdots, p\}$, where $x^*(i, j)$ represents the j-th index value of the i-th sample, n and p are the number of samples and indicators. For positive indicators, use the following equation for normalization.

$$x\left(i,j\right) = \frac{x^*\left(i,j\right) - x_{\min}\left(j\right)}{x_{\max}\left(j\right) - x_{\min}\left(j\right)} \tag{15}$$

Among them, $x\ (i,\ j)$ is the normalized sequence, and $x_{max}(j)$ and $x_{min}(j)$ are the maximum and minimum values of the j-th index value, respectively.

Next, construct a projection index function.

$$Q\left(a\right) = S_Z D_Z \tag{16}$$

Among them, $z(i)$ is the one-dimensional projection value, S_z is its standard deviation, and D_z is its local density. That is,

$$z\left(i\right) = \sum_{j=1}^{p} a\left(j\right) x\left(i,j\right), \quad i = 1, 2, \cdots, n \tag{17}$$

$$S_Z = \sqrt{\frac{\sum_{i=1}^{n}\left(z\left(i\right) - E\left(z\right)\right)^2}{n-1}} \tag{18}$$

$$D_Z = \sum_{i=1}^{n}\sum_{j=1}^{p}\left(R - r\left(i,j\right)\right) \times u\left(R - r\left(i,j\right)\right) \tag{19}$$

Among them, $E(z)$ is the average value of $z(i)$. R is the window radius of the local density, which can be determined through experiments. $r(i, j)$ represents the distance between samples. $u(t)$ is one-unit step function, when t≥0, its function value is 1, when t<0, its function value is 0. And $a(j)$ is the projection direction of p-dimensional data.

Finally, optimize the projection index function. Estimate the optimal projection direction by solving the projection index function maximization problem.

$$MaxQ(a) = S_z \times D_z \tag{20}$$

$$s.t. \sum_{j=1}^{p} a^2(j) = 1 \tag{21}$$

This is a complex nonlinear optimization problem, and it is difficult to estimate using traditional methods. This article uses an accelerated genetic algorithm based on real-coded to solve, which simulates the survival of the fittest and the chromosomal information exchange mechanism within the population. Projection pursuit model is programmed with Matlab R2017a.

C. STATIC AND DYNAMIC PANEL DATA MODEL

In order to examine the influence of the coupling coordination degree on economic development, this paper uses the coupling coordination degree as the explanatory variable and economic development as the explained variable to establish a complete static panel data model. Because the coupling coordination degree has a lagging effect on economic development, the explanatory variables are treated with a lag period. The measurement model is as follows.

$$Eco_{nt} = \alpha + \beta D_{nt-1} + \delta Control_{nt-1} + v_n + u_t + \varepsilon_{nt} \tag{22}$$

Among them, Eco_{nt} indicates the level of the economic development in the n-th region at time t. D_{nt-1} is the coupling coordination degree in the n-th region at time $t-1$, and its coefficient β measures the influence of the coupling coordination degrees on economic development, so it is the core parameter concerned in this article. If β is still significantly positive after controlling a series of provincial characteristic variables, it indicates that the coupling coordination degree will promote economic development, and vice versa. In addition, this article also controls the cross-section effect(v_n) and period effect(u_t) to alleviate the bias of missing variables. Finally, ε_{nt} is the random error term.

Although the static panel data model can control cross-section effect and period effect to obtain more robust estimation results, the static panel data model does not take into account the lag and continuity of economic development, and it is difficult to effectively solve the endogenous problem of explanatory variables, especially the coupling coordination degree. By introducing the lagging term of the explained variable into the static panel data model, building a dynamic panel data model can effectively capture the dynamic effects of economic development, better solve the endogenous problem of explanatory variables, and improve the robustness of the estimation results. Therefore, this paper introduces the first-order lag term of economic development on the basis of Equation (22), and constructs the following dynamic panel data model for research.

$$Eco_{nt} = \alpha + \beta_0 Eco_{nt-1} + \beta_1 D_{nt-1} + \delta Control_{nt-1} + v_n + u_t + \varepsilon_{nt} \tag{23}$$

IV. MEASUREMENT AND ANALYSIS OF THE COUPLING COORDINATION DEGREE

A. INDICATOR SYSTEM AND DATA DESCRIPTION

Government departments support innovation mainly by providing funding support and setting up innovation platforms [39]. ① Government departments provide funding support to innovation areas where market failure exists, and stimulate innovation activities by reducing costs and risks of innovation entities, thus promoting innovation [40]. Therefore, this paper selects the fiscal expenditure on science and technology as the indicator to measure the funding support of government departments. ② Government departments set up innovation platforms to promote the transformation of scientific and technological achievements and the development of innovation by providing innovation entities with sharing services of basic conditions, policy services, intermediary services and other innovation services. The Productivity Promotion Centres provides technical consultation, information consultation and intermediary services for middle and small-sized enterprises, and builds bonds among middle and small-sized enterprises and government, scientific research institutions, financial institutions to facilitate the mutual flow of knowledge, information and resources. Therefore, this paper selects the service statistics of state level Productivity Promotion Centres as the indicator to measure the support strength of Productivity Promotion Centres for innovation. Torch Specialized Industrial Bases is an important way to promote regional economic development and local scientific and technological work. Therefore, this paper selects the total number of employees of Torch Program Specialized Industrial Bases as the indicator to measure the support strength of Torch Specialized Industrial Bases for innovation. Torch Program Software Industry Bases can focus on their respective software industry advantages of the region, provide a good environment for software enterprises to innovate, and promote the innovation of software technology. Therefore, this paper selects the total number of employees of Software Industry Bases as the indicator to measure the support strength of Software Industry Bases for innovation. University Science Parks has realized the perfect connection between universities and high-tech enterprises, which is of great significance for accelerating the development of innovation. Therefore, this paper selects the number of tenants in University Science Parks as an indicator to measure the support of University Science Parks for innovation.

Financial institutions support innovation mainly by providing funding support and risk management services. ① The capital market has the function of financing funds and

TABLE 2. The indicator system of public Sci-tech finance, market sci-tech finance and technological innovation.

System Layer	First-level Indicator Layer	Second-level Indicator Layer	Unit
Government support (G)	Funding support (G_1)	Fiscal expenditure on science and technology (G_{11})	10^9 Yuan
	Innovation platform (G_2)	Service statistics of Productivity Promotion Centres (G_{21})	Item
		Total number of employees of Torch Program Specialized Industrial Bases (G_{22})	Person
		Total number of employees of Software Industry Bases (G_{23})	Person
		Number of tenants in University Science Parks (G_{24})	Unit
Financial support (F)	Funding support (F_1)	Total amount of financing in the capital market(F_{11})	10^9 Yuan
		Investment amount of venture capital (F_{12})	10^9 Yuan
		The contribution of financial institution in intramural expenditure on R&D (F_{13})	10^9 Yuan
	Risk management (F_2)	Scientific and technological insurance density (F_{21})	Yuan/person
Innovation (I)	Technological output (I_1)	Number of scientific and technological papers (I_{11})	Piece
		Number of patents granted (I_{12})	Item
	Economic output (I_2)	New product sales revenue (I_{21})	10^9 Yuan
		Technology market turnover(I_{22})	10^9 Yuan

dispersing risks. The multilevel capital market can provide financial support for innovation activities at different stages. Therefore, this paper selects the total amount of financing in the capital market by means of initial public offering, additional issuance, rights offering, as well as the issuance of preferred stock, convertible bond and exchangeable bond as the indicator to measure the support of capital market to innovation. Venture capital can provide long-term equity capital for innovation activities and provide management guidance for innovation entities. Therefore, this paper selects the investment amount of venture capital as the indicator to measure the support of venture capital to innovation. Loans belong to debt financing, and commercial banks are mainly suppliers. However, the assets of innovation entities are mostly intangible assets dominated by intellectual property rights and lack of fixed assets that can be mortgaged, so the available loans are limited. This paper selects the contribution of financial institution in intramural expenditure on R&D as the indicator to measure the support of bank credit to innovation. ② Scientific and technological insurance can effectively disperse and dissolve the high risk faced by innovation entities, and ensure the continuity and integrity of innovation activities. Therefore, this paper selects the scientific and technological insurance density as the indicator to measure the support of scientific and technological insurance to innovation.

Promote the development of innovation is the common goal of government support and financial support. Innovation activities have the characteristics of stages, and different stages have different innovation output. Therefore, this paper divides the innovation output into technological output and economic output. ① In the stage of research and development, innovation activities focus on research and experiments, and innovation outputs are mostly presented in the form of scientific and technological papers and patents. Therefore, this paper selects the number of scientific and technological papers and the number of patents granted as the indicators to measure the technological achievements. ② In the stage of achievement transformation and industrialization, the main task is how to make technological output into enterprises and industrial fields. At this time, innovation output is mainly economic output, which is mainly reflected in the sales situation of new products and the transaction situation of technology market. Therefore, this paper selects new product sales revenue and technology market turnover as indicators to measure economic output.

In summary, the indicator system of government support, financial support and innovation are shown in TABLE 2. The research sample of this paper are data of 28 provincial-level administrative regions in China from 2007 to 2016. Due to the serious lack of data in Hainan, Tibet, Qinghai, Hong Kong, Macao and Taiwan, they were excluded. The data are from *China Torch Statistical Yearbook, China Statistics Yearbook on High Technology Industry, China Statistical Yearbook on Science and Technology*, WIND database, PEdata and National Bureau of Statistics of China.

B. ANALYSIS OF THE COUPLING COORDINATION DEGREE

Based on the calculation of the coupling degree and the development degree, the coupling coordination degree of the provinces over the years can be obtained by using Equation (14) (as shown in TABLE 3). At the same time, in order to further analyze the differences in the coupling coordination degree among provinces, this paper classified the coupling coordination degree of each province in 2016 (as shown in Table 4).

On the whole, the coupling coordination degree in China is increasing year by year, but the absolute level of the

TABLE 3. The coupling coordination degree of 28 provinces in China from 2007 to 2016.

Province	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Beijing	0.52	0.45	0.52	0.58	0.59	0.58	0.60	0.72	0.76	0.78
Tianjin	0.22	0.20	0.18	0.21	0.22	0.26	0.28	0.28	0.31	0.29
Hebei	0.15	0.17	0.16	0.21	0.19	0.20	0.20	0.21	0.24	0.26
Shanghai	0.35	0.34	0.37	0.41	0.40	0.42	0.42	0.46	0.55	0.52
Jiangsu	0.38	0.41	0.40	0.47	0.52	0.56	0.58	0.62	0.67	0.72
Zhejiang	0.32	0.33	0.32	0.37	0.40	0.42	0.40	0.45	0.54	0.56
Fujian	0.20	0.20	0.17	0.22	0.22	0.22	0.26	0.27	0.32	0.32
Shandong	0.27	0.28	0.26	0.31	0.34	0.35	0.35	0.38	0.41	0.45
Guangdong	0.43	0.40	0.40	0.50	0.51	0.52	0.55	0.58	0.67	0.74
The average of eastern region	0.32	0.31	0.31	0.37	0.38	0.39	0.40	0.44	0.50	0.52
Shanxi	0.10	0.12	0.12	0.14	0.14	0.15	0.16	0.16	0.17	0.16
Liaoning	0.20	0.21	0.20	0.24	0.24	0.25	0.25	0.26	0.30	0.30
Jilin	0.12	0.12	0.14	0.15	0.15	0.17	0.18	0.17	0.19	0.21
Heilongjiang	0.17	0.16	0.16	0.19	0.18	0.20	0.20	0.21	0.23	0.24
Anhui	0.15	0.16	0.16	0.19	0.22	0.23	0.24	0.26	0.28	0.33
Jiangxi	0.11	0.11	0.12	0.17	0.15	0.17	0.18	0.18	0.20	0.23
Henan	0.16	0.17	0.16	0.19	0.20	0.23	0.24	0.26	0.28	0.30
Hubei	0.19	0.19	0.20	0.25	0.25	0.28	0.29	0.31	0.35	0.38
Hunan	0.15	0.17	0.16	0.20	0.21	0.22	0.24	0.25	0.27	0.27
The average of central region	0.15	0.16	0.16	0.19	0.19	0.21	0.22	0.23	0.25	0.27
Inner Mongolia	0.06	0.07	0.08	0.09	0.09	0.12	0.12	0.11	0.14	0.14
Guangxi	0.08	0.10	0.09	0.13	0.16	0.14	0.15	0.15	0.19	0.16
Chongqing	0.18	0.16	0.16	0.19	0.21	0.21	0.21	0.23	0.25	0.26
Sichuan	0.18	0.20	0.22	0.24	0.25	0.27	0.32	0.32	0.35	0.35
Guizhou	0.07	0.07	0.08	0.09	0.09	0.11	0.12	0.14	0.15	0.17
Yunnan	0.09	0.10	0.11	0.12	0.12	0.13	0.16	0.15	0.15	0.17
Shaanxi	0.16	0.21	0.19	0.24	0.23	0.26	0.28	0.30	0.32	0.33
Gansu	0.09	0.10	0.12	0.12	0.13	0.15	0.15	0.14	0.17	0.17
Ningxia	0.02	0.03	0.04	0.05	0.05	0.06	0.06	0.08	0.08	0.10
Xinjiang	0.08	0.10	0.10	0.13	0.13	0.12	0.13	0.13	0.15	0.17
The average of western region	0.10	0.11	0.12	0.14	0.15	0.16	0.17	0.18	0.19	0.20
The average of nationwide	0.19	0.19	0.19	0.23	0.24	0.25	0.26	0.28	0.31	0.32

coupling coordination degree is not high. The national mean value of the coupling coordination degree increased from 0.19 in 2007 to 0.32 in 2016, and the coupling coordination degree jumped from the stage of serious disorder to the stage of light disorder. This indicates that government support, financial support and innovation begin to form a virtuous circle of mutual support, mutual adjustment and mutual promotion. At the same time, the coupling coordination degree of the three regions showed an upward trend in fluctuations.

In the eastern region, the coupling coordination degree increased from 0.32 in 2007 to 0.52 in 2016, and has reached the stage of reluctance coordination. The overall growth is fast and the leading advantage is obvious. The coupling coordination degree of most provinces in the eastern region has entered the stage of transition and coordination. In particular, the coupling coordination degree of Beijing, Jiangsu and Guangdong has been in the stage of middle coordination. The reason may be that, during the study period, the provinces located in the eastern region had a higher level of economic development, frequent foreign trade, abundant resource endowments, so they were given greater support to innovation by government departments. The financial market in the eastern region are well-developed, and their modern financial system is constantly innovating and improving, which enables financial institutions to provide better support for innovation. Government departments and financial institutions have provided sufficient human, financial and material resources for innovation activities, thereby making the innovation in the eastern region develop rapidly. At the same time, the development of innovation will help increase the support of government departments and financial institutions.

TABLE 4. The classification of the coupling coordination degree of provinces in 2016.

Category	Provinces
Serious disorder (0.10-0.19)	Shanxi, Inner Mongolia, Guangxi, Guizhou, Yunnan, Gansu, Ningxia, Xinjiang
Moderate disorder (0.20-0.29)	Tianjin, Hebei, Liaoning, Jilin, Heilongjiang, Jiangxi, Hunan, Chongqing
Light disorder (0.30-0.39)	Fujian, Anhui, Henan, Hubei, Sichuan, Shaanxi
Near disorder (0.40-0.49)	Shandong
Reluctance coordination (0.50-0.59)	Shanghai, Zhejiang
Middle coordination (0.70-0.79)	Beijing, Jiangsu, Guangdong

Government support, financial support and innovation have formed a virtuous circle of mutual support and interaction.

In the central region, the coupling coordination degree increased from 0.15 in 2007 to 0.27 in 2016, showing a steady but rising development trend. The coupling coordination degree of most provinces in the central region is in the stage of moderate disorder and light disorder. In particular, the coupling coordination degree of Shanxi is still in the stage of serious disorder. The reason may be that, government support and financial support of the provinces in the central region are constrained by their own economic development, financial environment and factor endowment, so the two have insufficient support for innovation. As a result, government support and financial support for innovation is not effective, and the promotion effect of innovation on government support and financial support is also limited. The effect of mutual support and interaction among government support, financial support and innovation is weak and has not yet formed a well circular state.

In the western region, the coupling coordination degree rose from 0.10 in 2007 to 0.20 in 2016. The coupling coordination degree of each province increases year by year, but the level of the coupling coordination degree is still low. The coupling coordination degree in most provinces in the western region has been in a stage of serious disorder. Among them, the coupling coordination degree in Sichuan and Shaanxi is relatively good, and are in a stage of light disorder. The reason may be that, the economic environment in the western region is in the middle and the back of the country, the development of financial market is slow, the endowment of resources is insufficient. As a result, the support from government departments and financial institutions is relatively small, and its role in promoting the development of innovation is weak. The slow development of innovation has slowed the increase of support from government departments and financial institutions. The effects of mutual support and interaction among government support, financial support, and innovation are not obvious, and has not yet formed a circular state.

V. EMPIRICAL ANALYSIS OF THE RELATIONSHIP BETWEEN THE COUPLING COORDINATION DEGREE AND ECONOMIC DEVELOPMENT

A. VARIABLE SELECTION AND DATA DESCRIPTION

(1) Explained variable: economic development. Compared with a single indicator, the use of comprehensive indicators can measure research variables more comprehensively. Therefore, this paper selects regional GDP, regional per capita GDP, and household consumption level to measure economic development, and uses the projection pursuit model to reduce the dimension of high-dimensional data to obtain the only economic development measurement variable.

(2) Explanatory variable: the coupling coordination degree. The coupling coordination degree of government support, financial support, and innovation was calculated based on the equations above.

(3) Control variables. This paper controls a set of provincial characteristic variables in the regression model to alleviate the estimation bias caused by missing variables. This set of variables includes: the degree of openness to the outside world, which is measured by the total amount of imports and exports, expressed as *Open*. The level of information and communication, which is measured by the total volume of post and telecommunications services, expressed as *Inform*. The level of human capital, which is measured by fiscal education funds, expressed as *Edu*. The level of fixed asset investment, which is measured by the total amount of fixed asset investment in the whole society, expressed as *Fix*. The relevant data comes from the WIND database and the National Bureau of Statistics of China.

B. STATIONARITY TEST AND COINTEGRATION TEST

The regression analysis of panel data requires the data to be stationary. If non-stationary panel data is used for regression, false regression may occur, which may make the estimation results unreliable. Therefore, in order to avoid false regression and ensure the validity of the estimation results, this paper uses three unit root test method, LLC, Breitung, and PP-Fisher, to perform panel stationarity test before using static and dynamic panel data model for regression analysis (as shown in TABLE 5).

The results showed that the original sequences of all variables have unit roots to varying degrees, so unit root tests are performed on their first-order difference sequences. After the first-order difference, each variable at least passed two kinds of unit root tests at a confidence level of 1%, which indicates that each variable is integrated of order one. On this basis, Kao test is used to perform a cointegration test. The results showed that the null hypothesis is rejected at a significance level of 1%, that is, there is a cointegration relationship between variables. Therefore, the variables in this paper can be analyzed using static and dynamic panel data model.

TABLE 5. The results of unit root test.

Variables	Original sequence			First-order difference sequence		
	LLC test	Breitung test	PP-Fisher test	LLC test	Breitung test	PP-Fisher test
Eco	-6.90***	2.95	65.26	-10.35***	0.60	156.81***
D	-17.03***	-0.47	147.19***	-25.72***	-4.73***	258.14***
Open	-6.38***	2.73	34.19	-32.99***	-1.31	99.62***
Inform	-7.71***	-7.56***	43.57	-11.45***	-7.63***	120.97***
Edu	7.20	-0.36	9.35	-12.10***	-6.45***	114.99***
Fix	-4.67***	6.94	60.76	-11.65***	1.45	93.06***

Note: *, **, and *** indicate that they are significant at the significance level of 10%, 5%, and 1%, respectively.

C. MODEL ESTIMATION RESULTS AND DISCUSSION

Based on the panel data of 28 provinces in China from 2007 to 2016, this paper first estimates the static panel data model. The regression results are shown in Model 1-5 in TABLE 6. Among them, Model 1 is pooled regression model. Model 2 is cross-section fixed effect and period fixed effect model. Model 3 is cross-section fixed effect and period random effect model. Model 4 is cross-section random effect and period fixed effect model. Model 5 is cross-section random effect and period random effect model. The F test showed that the fixed effect model was better than the pooled regression model. The Hausman test showed that the fixed effect model was better than the random effect model. It can be seen that the regression results of Model 2 are more in line with the actual situation, so the following analysis is only performed on Model 2.

Based on the regression of the static panel data model, this paper also considers that there may be a certain path dependence in economic development, and adds a first-order lag term for economic development to establish a dynamic panel data model. The lagging term of the explained variable is introduced into the dynamic panel data model, so that the explanatory variable is related to the random error term. In addition, the explained variable and the explanatory variables may be causal to each other, which may cause serious endogenous problems in the dynamic panel data model. Therefore, this paper uses the GMM method to estimate Equation (23). In order to ensure the robustness of the results, this paper uses DIFF-GMM method and SYS-GMM method to examine the impact of the coupling coordination degree on economic development. The estimation results are shown in Model 6-7 in TABLE 6. Among them, Model 6 is DIFF-GMM model, and Model 7 is SYS-GMM model. Analyzing the estimated results of Model 6-7, the Wald test values are all significant at the level of 1%, rejecting the null hypothesis that the explanatory variable coefficients are all zero, which indicates that the overall fitting effect is well. The test values of AR (1) are less than 10%, and the test values of AR (2) are all greater than 20%, indicating that there is no second-order sequence correlation in the error terms of each dynamic panel data regression equation. Hansen test are all greater than 10%, indicating that the selection of instrumental variables for these models is effective. Therefore, the estimation results of the DIFF-GMM model and SYS-GMM model are consistent and reliable.

As shown in TABLE 6, the result of the static panel data model showed that the estimated coefficient of the coupling coordination degree is 1.46, and passed the significance test at the level of 1%. The results of DIFF-GMM method and SYS-GMM method of the dynamic panel data model showed that the estimated coefficients of the coupling coordination degree are 0.13 and 0.33, respectively, and both passed the significance test at the level of 1%. This shows that the coupling coordination degree of government support, financial support, and innovation can help promote economic development. As mentioned above, government support, financial support, and innovation achieve a spiral rise through the healthy coupling coordination of each other, so that the composite system composed of them can evolve to a higher level, thereby helping to promote economic development. The regression results of the dynamic panel data model in TABLE 6 also showed that the first-order lag terms of economic development are significant at a significance level of 1%, to a certain extent, indicating that there is a certain path dependence of economic development. The past economic development situation will affect the current economic development situation.

D. FURTHER RESEARCH: REGIONAL DIFFERENCES

In recent years, the economy has developed rapidly in China, but there are large differences in the level of development between regions. Is there a regional difference in the role of the coupling coordination degree in promoting economic development? This article intends to test this. Consistent with the above division criteria, this paper divides the whole into three sub-samples of the eastern region, the central region, and the western region to examine the regional differences in the impact of the coupling coordination degree on economic development. The estimated results of the static panel data model and dynamic panel data model are shown in TABLE 7.

Model 1, 4 and 7 are the estimation results of cross-section fixed effect and period fixed effect model in each region. Model 2, 5 and 8 are the estimation results of DIFF-GMM model in each region. And Model 3, 6 and 9 are the estimation

TABLE 6. Test of the influence of the coupling coordination degree on economic development.

Variables	Static panel data model					Dynamic pane data model	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
L.Eco						0.88***	0.96***
						(0.08)	(0.06)
D	1.61***	1.46***	1.87***	1.46***	1.78***	0.13*	0.33**
	(0.08)	(0.12)	(0.11)	(0.11)	(0.11)	(0.07)	(0.13)
Open	0.58***	0.23**	0.04	0.19**	0.02	-0.05	0.25
	(0.10)	(0.10)	(0.10)	(0.08)	(0.09)	(0.09)	(0.18)
Inform	-0.82***	0.09	-0.02	-0.01	-0.11	0.01	-0.28
	(0.10)	(0.08)	(0.07)	(0.07)	(0.08)	(0.05)	(0.42)
Edu	-0.09*	-0.02	0.04	-0.03	0.03	0.04*	-0.15
	(0.05)	(0.04)	(0.03)	(0.04)	(0.03)	(0.02)	(0.12)
Fix	0.30***	0.09*	0.21***	0.08*	0.21***	-0.09	-0.07
	(0.06)	(0.05)	(0.04)	(0.04)	(0.05)	(0.06)	(0.06)
_cons	0.06***	0.02	-0.08***	0.04**	-0.04	0.07**	0.04
	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)	(0.03)	(0.03)
Cross-section effect	no	yes	yes	yes	yes	yes	Yes
Period effect	no	yes	yes	yes	yes	yes	Yes
Obs	280	280	280	280	280	280	280
Adjusted R^2	0.79	0.98	0.96	0.92	0.70		
Wald(p-value)						0.00	0.00
AR(1)(p-value)						0.06	0.06
AR(2)(p-value)						0.90	0.65
Hansen(p-value)						0.16	0.86

Note: *, **, and *** indicate that they are significant at the significance level of 10%, 5%, and 1%, respectively. Numbers in parentheses are the corresponding standard errors.

TABLE 7. Test of the influence of the coupling coordination degree on economic development: Estimated results by region.

Variables	Eastern region			Central region			Western region		
	Static	Dynamic		Static	Dynamic		Static	Dynamic	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
L.Eco		0.95***	0.98***		0.42**	0.76***		0.79*	0.99***
		(0.06)	(0.08)		(0.19)	(0.19)		(0.41)	(0.09)
D	1.31***	0.30***	0.26**	0.31	-0.36	0.01	0.32	0.22	0.17
	(0.19)	(0.08)	(0.10)	(0.21)	(0.25)	(0.25)	(0.24)	(0.21)	(0.18)
Control Variables	yes	Yes	yes	yes	yes	yes	yes	yes	yes
Cross-section effect	yes	Yes	yes	yes	yes	yes	yes	yes	yes
Period effect	yes	yes	yes	yes	yes	yes	yes	yes	yes
Obs	90	90	90	90	90	90	100	100	100
Adjusted R-square	0.97			0.98			0.97		
Wald(p-value)		0.00	0.00		0.00	0.00		0.00	0.00
AR(1)(p-value)		0.07	0.09		0.06	0.02		0.06	0.06
AR(2)(p-value)		0.17	0.44		0.13	0.16		0.70	0.54
Hansen(p-value)		0.28	0.96		0.13	0.95		0.27	0.44

Note: *, **, and *** indicate that they are significant at the significance level of 10%, 5%, and 1%, respectively. Numbers in parentheses are the corresponding standard errors.

results of SYS-GMM model in each region. The goodness of fit of the static panel data model is above 0.95, indicating that the setting of the static panel data model is reasonable. The dynamic panel data model passed the Wald test, AR (1) test, AR (2) test and Hansen test, so the estimation results of the dynamic panel data model are consistent and valid.

The coefficient of influence of the coupling coordination degree on economic development in the eastern region is significantly positive, while that in the central and western region is not significant. This indicates to some extent that there is a regional difference in the effect of the coupling coordination degree on economic development. The possible reason is that, the eastern region is at the forefront of reform and opening up. Government departments have provided great funding and policy support for its innovation activities. The well-developed financial system has provided good financial support and risk management services for innovation activities. It will help the eastern region to attract high-tech enterprises and talents, and promote the rapid development of innovation. Government support, financial support, and innovation have developed together in the process of interaction, achieving a state of healthy coupling coordination, which helps promote economic development. In the central and western region, the level of government support, the degree of financial system development, and the level of innovation development are all weak. The interaction between the three has not yet formed a healthy coupling coordination state, so its role in promoting economic development is not obvious.

VI. CONCLUSIONS

Based on the theoretical analysis of the coupling mechanism of government support, financial support, and innovation, this paper uses the panel data of 28 provinces in China from 2007 to 2016 to calculate the coupling coordination degree of government support, financial support, and innovation using the coupling coordination degree model. Based on this, this paper uses projection pursuit model, static panel data model and dynamic panel data model to empirically test the impact of the coupling coordination degree on economic development. The main research findings are as follows.

First, from a national perspective, the coupling coordination degree of government support, financial support and innovation is increasing year by year, but the absolute level of the coupling coordination degree is not high. From the regional perspective, the coupling coordination degree has increased rapidly and has an obvious leading advantage in the eastern region. The coupling coordination degree is in a stable development trend in the central region. The coupling coordination degree is increasing year by year in the western region, but the grade of the coupling coordination degree is still low, and it has been in the stage of serious disorder in most cities.

Second, the coupling coordination degree has a significant positive impact on economic development, that is, the coupling coordination degree helps promote economic development. Further research finds that there are regional differences in the role of the coupling coordination degree in promoting economic development. That is, the coupling coordination degree significantly promotes the economic development of the eastern region, but its impact on the economic development of the central and western region is not obvious.

Based on the above research results, in order to improve the coupling coordination degree of government support, financial support and innovation, and promote economic development, this paper makes the following recommendations.

First, for government support, on the one hand, the government should increase the fiscal expenditure of science and technology, improve the capital shortage problem of innovation entities in the process of innovation. And it is ought to cultivate innovation platforms such as Productivity Promotion Centers and Torch Program Specialized Industrial Bases to improve the innovation capacities and efficiency of innovation entities. On the other hand, government departments should pay attention to the areas of its support, and avoid the negative impact of unreasonable government support on financial support and innovation.

Second, for financial support, it is ought to constantly innovate and improve the multilevel capital market, improve the financing system of the capital market, optimize the service function of the capital market, and make it provide financing opportunities for more innovative entities. And it also should expand the sources of capital for venture capital, build large-scale venture capital, and provide financial support for innovation entities. It can gradually liberalize interest rates on loans to ensure that the risks banks take match the returns they receive, and increase their willingness to lend to innovative entities. Then it also can promote the development of scientific and technological insurance and innovate scientific and technological insurance products to provide risk management services for all stages of innovation activities.

Third, for innovation, on the one hand, government departments should increase the expenditure of educational funds to cultivate innovative talents for and innovation entities. On the other hand, government departments should improve relevant legislation on intellectual property protection, crack down on intellectual property infringement, and protect the rights and interests of relevant stakeholders. In this way, the effects of government support and financial support can be guaranteed, so as to realize the joint development of government support, financial support and innovation, and then realize development of the coupling coordination degree, promote economic development.

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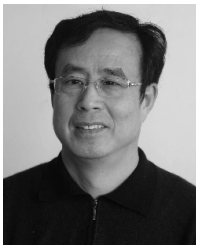

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