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Optimization of the Dynamic Measure in Spillover Effect Based on Knowledge Graph

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This paper improves the dynamic Feder model based on the characteristics of knowledge production and separates the direct effect and spillover effect of R&D in order to determine the relationship between spillover effect of R&D and economic growth, and accurately measure it by examining Chinese provincial panel data from 2008–2016. The theoretical analysis shows that the spillover effect of R&D promotes economic growth. Empirical analysis using a combination of OLS, sysGMM, 2SLS and GLS shows that basic research and application research have significant spillover effects; the marginal revenue of the basic research is lower than that of the production sector, while the marginal revenue of the application research is higher than that of the production sector; and knowledge stock does not significantly promote innovation in China. However, any study on the influence of knowledge stock on innovation entails more than basic research.

Keywords: R&D; Spillover Effect; Improved Dynamic Feder Model

1. INTRODUCTION

The new economic growth theory holds that the spillover effect of R&D is an important factor in promoting economic growth, and is an engine that sustains long-term economic growth and overcomes diminishing returns. [1–3] The measurement of the spillover effect of R&D has always been a research direction. It is generally believed that the common methods for measuring the spillover effects of R&D are as follows: first, from the perspective of knowledge production, Griliches proposed using the C-D production function to describe the process of knowledge production; [4] Jaffe, on this basis, created a Griliches-Jaffe production function to measure the spillover effect by introducing a spillover effect variable. [5] Since then, many researchers have expanded on and based their analyses on this function. [6–7] The second method used for measuring the spillover effect of R&D entails the estimation of total factor productivity (TFP). However, the definition of TFP itself is not very clear, and technology cannot be directly separated from TFP. The third is the extreme boundary analysis suggested by Leamer, [8] using the economic growth rate as the main indicator for evaluating knowledge spillovers to establish the impact of knowledge spillovers and other variables on economic growth rate. Fourth, the cost function method proposed by Bernstein [9] measures the intensity of knowledge spillover by analyzing the input and cost reduction caused by this spillover. With the development of econometrics, new measurement methods, such as spatial econometrics, [10] dynamic panel data, [11] quantile regression, [12] provide various means of measuring the spillover effect of R&D.

The literature analysis indicates that there are two issues needing to be addressed.

First, most studies have examined spillover effects under the paradigm of the Griliches-Jaffe production function. There

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are not many breakthroughs in research methods, and the Griliches-Jaffe research paradigm itself has some shortcomings. For example, the Griliches-Jaffe production function considers only the spillover effects of R&D, ignores the direct effects of R&D, and causes bias in the measurement of spillover effects. In addition, the Griliches-Jaffe production function needs to calculate the stock of related variables, but the calculation of stocks is also highly controversial.[13] In order to solve these problems, this paper establishes a new theoretical research method that is an improved dynamic Feder model which simultaneously incorporates the direct effects and spillover effects of R&D into the model research. Controlling the direct effect and other variables of R&D, the spillover effect of R&D is measured to reduce the bias of spillover effect measurement.

Second, the forms of R&D output are diverse, and the effects and mechanisms of different R&D outputs on economic growth are quite different. Roper and other scholars divide the innovation process into three stages[14]: knowledge acquisition, knowledge transformation and knowledge development. Pang divides it into two stages: innovation resource transformation and innovation knowledge transformation. According to the relationship between input and output of factors, Li divides the innovation process into the stage of technology development and the stage of transformation of results.[15] From the perspective of the narrow innovation chain, this paper divides the R&D output into basic R&D output and applied R&D output, and correspondingly divides the R&D sector into basic R&D sector and applied R&D sector. Basic R&D refers mainly to the research and development of new knowledge and new technologies. The outputs include scientific papers, academic monographs, patents, etc. Applied R&D mainly refers to the development of new products and processes using new knowledge and new technologies until commercial application, the outputs are new products. This paper attempts to discuss the relationship between different R&D sectors and economic growth and measures its spillover effects from the perspective of R&D output.

This paper improves the dynamic field model and separates the direct effect and spillover effect of R&D, so as to facilitate the accurate measurement of spillover effect. According to the diversity of R&D outputs, this paper divides the R&D sector into basic R&D sector and applied R&D sector, and measures the spillover effects of different R&D sectors. The model shows the spillover effect of R&D promotes economic growth; the empirical studies shows that the spillover effect of basic R&D and applied R&D significantly promotes economic growth. In China, the marginal return of factors of the basic R&D sector is lower than that of the production sector, while the applied R&D sector's is higher than that of the production sector; the knowledge stock does not play a significant role in promoting innovation. To be specific, the knowledge stock of applied R&D has a spillover effect, while the knowledge stock of basic R&D has a drag-out effect.

The remainder of the paper is organized as follows: section 1 describes an improved dynamic Feder model and discusses the relationship between R&D spillover effects and economic growth; section 2 presents the empirical strategy and the dataset used; section 3 measures spillover effects of basic R&D and applied R&D and calculates other parameter values; section 4 presents the comparative analysis of parameters and the explanation of their microscopic mechanism; section 5 concludes the paper.

2. MODELING

The paper assumes that the economy consists of only two sectors: the R&D sector and the production sector. The output of the R&D sector can directly drive economic growth. At the same time, the output of the R&D sector also promotes the production sector to improve technology and efficiency, reduce costs, and indirectly promote economic growth. Based on the idea of Feder, [16] the production function of the two sectors is constructed as follows:

$$A_t = A(K_{A_t}, L_{A_t}) \tag{1}$$

$$P_t = P(K_{P_t}, L_{P_t}, A_t) \tag{2}$$

$$Y_t = A_t + P_t \tag{3}$$

and,

$$K_t = K_{P_t} + K_{A_t} \tag{4}$$

$$L_t = L_{P_t} + L_{A_t} \tag{5}$$

where Y_t is the total output of the economy, P_t is the output of the production sector and A_t is the output of the R&D sector. We assume that the economy has only two production factors, namely capital K_t and labor L_t, where capital K_{A_t} and labor L_{A_t} are allocated to the R&D sector, and the output is A_t; capital K_{P_t} and labor L_{P_t} are allocated to the production sector, and the output is P_t, which is also affected by A_t.

In order to apply the Feder model to the R&D sector, we must follow the law of knowledge production and need improvements in two ways:

First, we address the improvement of the knowledge production function A_t. Griliches first proposed the knowledge production function from the perspective of R&D input and output, and believed that knowledge production is a function of knowledge stock. This paper adopts this idea, so equation (1) becomes:

$$A_t = A(K_{A_t}, L_{A_t}, {A_t}^{\#})$$

where ${A_t}^{\#}$ represents the knowledge stock in period t. The knowledge stock is the accumulation of knowledge production in each period. Therefore, the lag of knowledge production in each period has an impact on the current knowledge production. This study is based on the idea of Griliches: that A_{t-s} has the greatest impact on knowledge production and replaces the knowledge stock ${A_t}^{\#}$ with it. Thus, the knowledge production function becomes:

$$A_t = A(K_{A_t}, L_{A_t}, A_{t-s})$$

From the perspective of empirical research, the larger is the s, the more samples are lost, which is not conducive to parameter estimation. Therefore, without affecting the main conclusions, we assume that s=1, the above equation becomes:

$$A_t = A(K_{A_t}, L_{A_t}, A_{t-1}) \tag{6}$$

Second, an improvement on the production function P_t. From equation (2) we know that the output of the production sector P_t is affected only by the current period knowledge production A_t. In fact, due to the existence of technical hysteresis, A_t of each period will have an impact on the current output of the production sector P_t, that is, a spillover effect. Estimating only with the current A_t, we will ignore the spillover of the R&D sector and underestimate the role of the R&D sector. In order to solve the problems above, we replace equation (2) with:

$$P_t = P(K_{P_t}, L_{P_t}, A_t*) \quad (7)$$

$$A_t{}^* = \alpha_0 A_t + \alpha_1 A_{t-1} + \cdots \quad (8)$$

where $A_t{}^*$ is the spillover factor of the R&D sector to the production sector of period t. From the expression, $A_{t-i}()$ has a spillover effect on P. The introduction of $A_t{}^*$ makes the Feder model dynamic, which is more in line with economic reality. However, there are too many variables in equation (7), and the degree of freedom is reduced, which is not conducive to theoretical and empirical analysis. Therefore, borrowing the idea of the Bao, [17] we introduce the adaptive expectation model to our model and assume that the spillover factor of period t $A_t{}^*$is not only related to A_t, but is also related to the spillover factor of period t-1 $A_{t-1}{}^*$; then equation (8) becomes:

$$A_t{}^* = \theta A_t + (1-\theta)A_{t-1}{}^* = \theta \sum_{i=0}^{\infty} (1-\theta)^i A_{t-i} \quad (9)$$

where $0 < \theta \leq 1$

Thus, the improved dynamic Feder model is composed of equations (3), (6), and (7). Taking the derivative of equations (6) and (7), we have:

$$dA_t = \frac{\partial A_t}{\partial K_{A_t}} dK_{A_t} + \frac{\partial A_t}{\partial L_{A_t}} dL_{A_t} + \frac{\partial A_t}{\partial A_{t-1}} dA_{t-1} \quad (10)$$

$$dP_t = \frac{\partial P_t}{\partial K_{P_t}} dK_{P_t} + \frac{\partial P_t}{\partial L_{P_t}} dL_{P_t} + \frac{\partial P_t}{\partial A_t{}^*} dA_t{}^* \quad (11)$$

where $\frac{\partial A_t}{\partial K_{A_t}}$ and $\frac{\partial A_t}{\partial L_{A_t}}$ are the marginal returns on capital and labor of the R&D sector, respectively, $\frac{\partial P_t}{\partial K_{P_t}}$ and $\frac{\partial P_t}{\partial L_{P_t}}$ are the marginal returns on capital and labor of the production sector. According to Bruno's hypothesis, [18] the relationship between the marginal returns of capital and labor in the two sectors is:

$$\frac{\partial A_t}{\partial K_{A_t}} \Big/ \frac{\partial P_t}{\partial K_{P_t}} = 1+\sigma \qquad \frac{\partial A_t}{\partial L_{A_t}} \Big/ \frac{\partial P_t}{\partial L_{P_t}} = 1+\delta$$

where σ denotes the difference in the marginal return on capital of the R&D sector and the production sector, and δ denotes the difference in the marginal return on labor of the R&D sector and the production sector. For the sake of simplicity, we assume $\sigma = \delta$. Then we have:

$$\frac{\partial A_t}{\partial K_{A_t}} \Big/ \frac{\partial P_t}{\partial K_{P_t}} = \frac{\partial A_t}{\partial L_{A_t}} \Big/ \frac{\partial P_t}{\partial L_{P_t}} = 1+\sigma \quad (12)$$

If the marginal return of the factors of the R&D sector is higher than that of the production sector, that is $\sigma > 0$, the factors will flow to the R&D sector. If the R&D sector's is lower than the production sector's, that is $\sigma < 0$, the factors will flow to the production sector; if the R&D sector's is the same as the production sector's, that is $\sigma = 0$, the factors do not flow.

Taking the derivative of equation (3), and substituting equation (10), equation (11) and equation (12), we have:

$$dY_t = dA_t + dP_t = \frac{\partial P_t}{\partial K_{P_t}} dK_t + \frac{\partial P_t}{\partial L_{P_t}} dL_t + \frac{\sigma}{1+\sigma} dA_t + \frac{1}{1+\sigma} \frac{\partial A_t}{\partial A_{t-1}} dA_{t-1} + \frac{\partial P_t}{\partial A_t{}^*} dA_t{}^* \quad (13)$$

Based on the ideas of Feder, the following assumptions were made:

a. In the production sector, the impact of the spillover factor on the production sector satisfies the constant output elasticity:

$$P_t = (A_t{}^*)^{\omega} f_1(K_{P_t}, L_{P_t}) \quad (14)$$

ω represents the spillover effect of the R&D sector on the production sector. Grossman and Helpman believe that the R&D sector drives the production of other sectors and promotes economic growth. [2] Knowledge has positive externality, that is, $\omega > 0$.

b. In the knowledge production sector, the knowledge stock (substituted by the knowledge production with a lag of 1 period A_{t-1}) also satisfies the constant output elasticity of the current knowledge production:

$$A_t = A_{t-1}{}^{\gamma} f_2(K_{A_t}, L_{A_t}) \quad (15)$$

γ represents the impact of knowledge stock on knowledge production, that is, innovation. Past discoveries may provide ideas and tools that make it easier to innovate, in this case, $\gamma > 0$, which is the spillover effect of the knowledge stock. If more discoveries in the past make innovation more and more difficult, in this case, $\gamma < 0$, this is the Fishing-out Effect of the knowledge stock. If past discoveries have nothing to do with innovation, then $\gamma = 0$. Using equations (14) and (15), we obtain:

$$\frac{\partial P_t}{\partial A_t{}^*} = \omega \frac{P_t}{A_t{}^*} \quad (16)$$

$$\frac{\partial A_t}{\partial A_{t-1}} = \gamma \frac{A_t}{A_{t-1}} \quad (17)$$

We substitute equation (16) and equation (17) into equation (13) and divide both sides by Y_t, and have:

$$\frac{dY_t}{Y_t} = \frac{\partial P_t}{\partial K_{P_t}} \frac{dK_t}{Y_t} + \frac{\partial P_t}{\partial L_{P_t}} \frac{L_t}{Y_t} \frac{dL_t}{L_t} + \frac{\sigma}{1+\sigma} \frac{A_t}{Y_t} \frac{dA_t}{A_t} + \frac{\gamma}{1+\sigma} \frac{A_t}{Y_t} \frac{dA_{t-1}}{A_{t-1}} + \omega \frac{P_t}{Y_t} \frac{dA_t{}^*}{A_t{}^*} \quad (18)$$

We substitute equation (9) into equation (18), and use geometric lag transformation, and have:

$$\frac{dY_t}{Y_t} = \theta \frac{\partial P_t}{\partial K_{P_t}} \frac{dK_t}{Y_t} + \theta \frac{\partial P_t}{\partial L_{P_t}} \frac{L_t}{Y_t} \frac{dL_t}{L_t} + \frac{\sigma\theta}{1+\sigma} \frac{A_t}{Y_t} \frac{dA_t}{A_t} + \frac{\gamma\theta}{1+\sigma} \frac{A_t}{Y_t} \frac{dA_{t-1}}{A_{t-1}} + \omega\theta \frac{P_t}{Y_t} \frac{dA_t}{A_t} + (1-\theta) \frac{dY_{t-1}}{Y_{t-1}} \quad (19)$$

From equation (19), the following proposition can be obtained after analysis: the spillover effect of R&D sector promotes economic growth.

$\frac{P_t}{Y_t} \frac{dA_t}{A_t} = \left(\frac{dA_t}{dP_t} \frac{P_t}{A_t}\right)\left(\frac{P_t}{Y_t} \frac{dP_t}{P_t}\right)$ is the product of the elastic of the R&D sector to the production sector $\frac{dA_t}{dP_t} \frac{P_t}{A_t}$ and the contribution of the production sector to the total social output $\frac{P_t}{Y_t} \frac{dP_t}{P_t}$. It represents the indirect contribution of the R&D sector to the total social output through the production sector; that is, the spillover effect of the R&D sector. Due to the existence of externalities, the value of R&D output is often not fully reflected in the direct economic benefits. Part of the value indirectly improves the benefits of the absorber through the diffusion and dissemination of R&D output, and indirectly continues to promote economic development. The contribution of R&D spillovers to economic growth through the production sector depends on $\omega\theta$. As can be seen from equations (9) and (15), $\theta > 0$, $\omega > 0$, thus $\omega\theta > 0$; hence, R&D spillovers promote economic growth.

3. ECONOMETRIC MODEL AND DATA

3.1 Econometric Model

According to the prompts of equation (19), the econometric model for determining the dynamic measurement of R&D spillover effect is:

$$y_{i,t} = \beta_0 + \beta_1 A_{i,t\_spil} + \beta_2 k_{i,t} + \beta_3 l_{i,t} + \beta_4 A_{i,t\_dir} + \beta_5 A_{i,t-1} + \beta_6 y_{i,t-1} + \varepsilon_{i,t} \tag{20}$$

where i denotes province i, t denotes year t,

$$\beta_1 = \omega\theta, \quad \beta_4 = \frac{\sigma\theta}{1+\sigma}, \quad \beta_5 = \frac{\gamma\theta}{1+\sigma}, \quad \beta_6 = 1-\theta$$

After arranging, we have:

$$\theta = 1-\beta_6, \quad \omega = \frac{\beta_1}{1-\beta_6}, \quad \sigma = \frac{\beta_4}{1-\beta_6-\beta_4}, \tag{21}$$

$$\gamma = \frac{\beta_5}{1-\beta_6-\beta_4} \tag{22}$$

The econometric model (22) forms a dynamic panel model, which has the advantage of controlling the endogeneity caused by missing variables.

3.2 Variable Description and Data Processing

In equation (22), the dependent variable is $y_{i,t} = \frac{dY_{i,t}}{Y_{i,t}}$, which represents the economic growth rate of province i in year t.

$A_{i,t\_spil} = \frac{P_{i,t}}{Y_{i,t}}\frac{dA_{i,t}}{A_{i,t}}$ represents the spillover effect of R&D, which is the core explanatory variable, $A_{i,t\_dir} = \frac{A_{i,t}}{Y_{i,t}}\frac{dA_{i,t}}{A_{i,t}}$ represents the direct effect of R&D, and $A_{i,t}$ is the R&D output. Ljungwall and Beaudreau take the R&D expenditure as the proxy variable of R&D. [19–20] In this study, we take the R&D output as the proxy variable. However, R&D output has various forms, and the mechanism and effect of different levels of R&D output on economic growth are completely different. From the perspective of narrow innovation chain, this paper divides R&D output into two different levels, basic R&D output and applied R&D output. Generally, the researcher takes the number of patent authorizations or applications as the proxy variable of basic R&D output. However, according to equation (22), R&D output must be comparable to the GDP, so a proxy variable measured by currency must be selected. Teitez believes that technology market transaction refers to the transfer of patent rights, transfer of patent application rights, patent licensing and use, and transfer of technical secrets between parties. Technology market turnover, which is the embodiment of the monetization degree of technology market transactions, can represent not only the development intensity of basic R&D, but also the degree of commercialization of basic R&D. Therefore, in this study, we choose the technical market turnover as the proxy variable based on R&D (Figure 1). The results of applied R&D are in the form of new products. This study follows the practice of Wu and takes the total sales of new products as the measurement index for applied R&D (Figure 2). [21]

$l_{i,t} = \frac{dL_{i,t}}{L_{i,t}}$ is the growth rate of labor force of province i in year t. Labor force is the traditional input factor of economic growth. This study adopts the practice of Li and Zheng, using population growth rate as the proxy variable of labor; $k_{i,t} = \frac{K_{i,t}}{Y_{i,t}}$ is the investment of province i in year t. Generally speaking, the larger the investment scale is, the more it is used for the accumulation of material capital and the faster will be the economic growth. According to equation (19) and the treatment methods of Wang and Liu, [22] the investment scale is defined as the proportion of the total fixed asset investment in the GDP of the whole society.

3.3 Data

Among the data used in this paper, the data of gross national product (GDP), total population and total fixed asset investment of the whole society are all from China statistical yearbook. Data of technology market turnover and total sales of new products are from China science and technology statistical yearbook. In the China Science and Technology Statistical Yearbook, the provincial panel data for total sales of new products are reported from 2008. Therefore, in the empirical studies of applied R&D output, the sample interval is from 2008 to 2016. Among them, the data for total sales of new products in 2010 are missing and we replace these with the average of 2009 and 2011. In the empirical studies of basic R&D output, the sample interval of provincial panel data is from 2008 to 2014. Among them, the data of the technical market turnover of Tibet is missing, so it was omitted. National time series data on the variables are reported from 1993, so the sample interval is from 1993 to 2016. Finally, in order to ensure comparable data, all indicators are subject to constant price adjustments based on 1978.

4. THE EMPIRICAL ANALYSIS

4.1 Measurement of Spillover Effects of Basic R&D

According to the provincial panel data collected from 2005 to 2014, in this section we first use mixed least square (mixed OLS) to estimate it to obtain the benchmark model (1). It can be seen from the results that the spillover effect of basic R&D significantly promotes economic growth. However, the mixed panel model did not take individual heterogeneity into consideration. Therefore, we then use the sys-GMM method for estimation and obtain model (2).

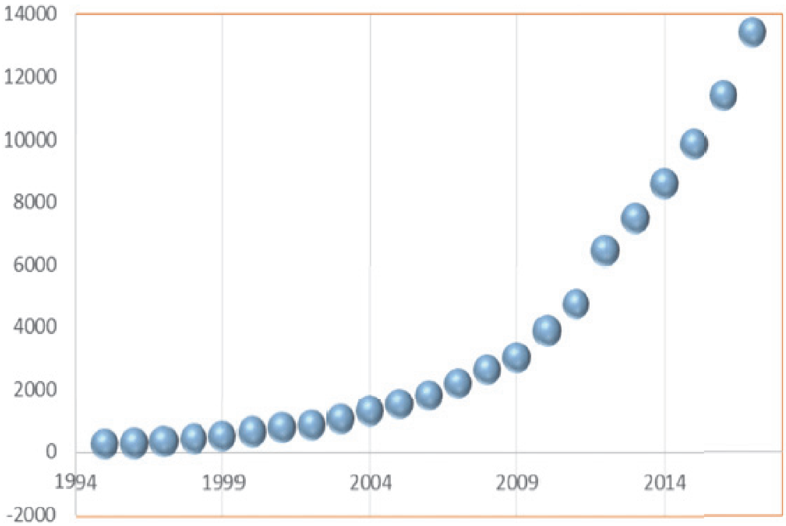

Figure 1 Turnover in technology market (100 million yuan).

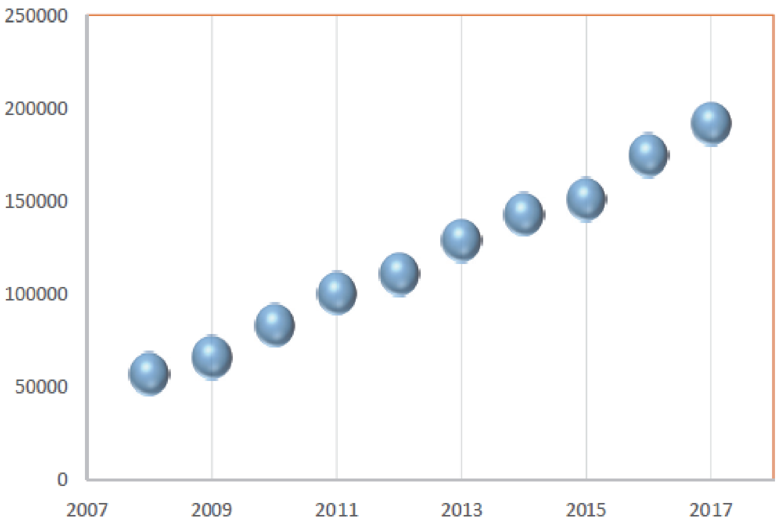

Figure 2 New product revenue (10 thousand yuan).

Table 1 Regression analysis and parameter calculation table of basic research and development.

VAR	(1) Mixed OLS	(2) sysGMM	(3) sysGMM	(4) sysGMM	(5) sysGMM	(6) 2SLS	(7) GLS	
$A_{i,t_{spil}}$	0.131***	0.244	0.555***	0.460***	0.361***	0.366***	0.334**	ω=0.580
(2.82)	(1.58)	(2.68)	(2.55)	(2.73)	(2.81)	(2.18)		
$k_{i,t}$	−0.013	−0.111*	−0.098*	−0.104***	−0.090**	−0.091**	−0.070***	
	(−0.78)	(−1.84)	(−1.78)	(−2.75)	(−2.29)	(−2.28)	(−3.73)	
$l_{i,t}$	0.294	1.545	1.919*	1.739*	1.545*	1.559*	−6.047***	
	(1.13)	(1.10)	(1.76)	(1.83)	(1.88)	(1.88)	(−3.86)	
$A_{i,t_{d}ir}$	−1.304	−4.864	−9.972**	−6.985***	−3.281**	−3.004*	−12.850	$\sigma = -0.841$
	(−1.35)	(−1.63)	(−2.39)	(−2.58)	(−2.25)	(−1.69)	(−1.25)	
$A_{i,t-1}$	−0.017	−3.116	−1.894	0.419	−0.069	−0.032	2.424***$\gamma = -$	$\gamma = -0.018$
	(−0.02)	(−1.54)	(−1.18)	(0.50)	(−0.07)	(−0.04)	(2.46)	
$y_{i,t-1}$	0.531***	0.289**	0.333***	0.348***	0.377***	0.370***	0.678***	θ=0.622
	(8.31)	(2.23)	(2.74)	(3.57)	(4.01)	(3.89)	(10.90)	
C	0.051***	0.150**	0.131**	0.127***	0.111***	0.111***	0.098***	
	(3.35)	(2.40)	(2.49)	(3.18)	(2.65)	(2.63)	(4.52)	
Obs.	210	210	210	210	210	210	22	
$R - sqr$	0.289						0.982	
Autoreg.		−3.667***	−3.326***	−2.818**	−1.566*			
Sargan		27.56***	29.37	28.99	29.23			

Note: The brackets in models (2), (3), (4), (5), and (6) are the Z values of the estimated parameters. The brackets in models (1) and (7) are the t values of the estimated parameters. *, **, *** are significant at the 10%, 5%, and 1% levels, respectively.

Table 2 Regression analysis and parameter calculation table of applied research and development.

VAR	(8) Mixed OLS	(9) sysGMM	(10) sysGMM	(11) sysGMM	(12) sysGMM	(13) 2SLS	(14) OLS	
$Ai, t_s pil$	0.133*	0.253*	0.665*	0.390***	0.345***	0.262***	0.479*	ω=0.133
	(1.69)	(1.78)	(1.88)	(2.17)	(2.22)	(2.15)	(1.77)	
ki, t	0.801***	0.902***	0.824***	0.893***	0.825***	0.812***	0.974***	
	(2.01)	(2.23)	(2.06)	(2.24)	(2.10)	(2.06)	(2.00)	
li, t	0.070	−1.965	−2.429	−1.755	−1.012	−0.851	5.797	
	(0.24)	(−0.88)	(−1.07)	(−0.98)	(−0.78)	(−0.80)	(1.29)	
$Ai, t_d ir$	0.077	0.254	0.489	0.246	0.197	0.151	2.398***	σ=3.254
	(0.70)	(0.80)	(1.39)	(0.75)	(0.77)	(0.68)	(3.37)	
$Ai, t-1$	0.026	0.106	0.110	0.053	0.026	0.030	0.510	γ=0.434
	(0.40)	(1.02)	(1.35)	(0.63)	(0.32)	(0.36)	(0.93)	
$yi, t-1$	0.739***	0.737***	0.767***	0.736***	0.741***	0.76***	0.379**	θ=0.259
	(15.34)	(6.32)	(6.06)	(6.69)	(7.93)	(11.85)	(2.19)	
C	0.030	0.235	0.126	0.229	0.126	0.062	0.02	
	(0.26)	(0.47)	(0.26)	(0.53)	(0.40)	(0.27)	(0.04)	
Obs.	124	124	124	124	124	124	22	
R-sqr	0.6779						0.7534	
Autoreg.		1.9209*	1.3633	1.7502*	1.7345*			
Sargan		23.77***	24.36***	26.53**	27.25			

A. Endogenous Test

Endogeneity will lead to the bias of variable estimation and even the distortion of economic meaning, so it is necessary to control the endogeneity of the model. The dynamic panel model takes into account the endogeneity caused by the omission of variables, but there may be bidirectional causality between the spillover effect (A_{i,t_spil}) and direct effect (A_{i,t_dir}) of R&D, and between $A_{i,t-1}$] and $A_{i,t-1}$, and then there may be endogeneity. Therefore, we take the lag of each variable as its instrumental variable in this section to control endogeneity.

B. Robustness Test

In the process of controlling endogeneity, the model (1)–(5) has reached a consistent conclusion that the spillover effect of basic R&D significantly promotes economic growth. In order to continue to explore the robustness of the conclusion, in this section we first use the two-stage least square method (2SLS) to estimate it and obtain model (6), and then use the time series data from 1993 to 2014 to obtain model (7). The results both show that the spillover effect of basic R&D significantly promotes economic growth. Therefore, from the above analysis, we know that the spillover effect of basic R&D significantly promotes economic growth, and the conclusion is robust.

C. Parameter calculation

After controlling the endogeneity of the variables and testing their robustness, the parameter estimation of model (5) is adopted to calculate the parameters in equation (23), and we have:

$$\sigma = -0.8405, \quad \omega = 0.058, \quad \gamma = 0.0177 \tag{23}$$

4.2 Measurement of Spillover Effects of Application R&D

We use the method similar to that in the previous section for parameter estimation, and perform endogenous and robustness tests. The results are shown in Table 2. It is found that the spillover effect of applied R&D can significantly promote economic growth. By using the parameter estimation of model (12) and calculating the parameters in equation (23), we have:

$$\sigma = 3.2535, \quad \omega = -0.1333, \quad \gamma = 0.4340 \tag{24}$$

5. PARAMETER COMPARISON AND MICROCOSMIC MECHANISM ANALYSIS

5.1 Comparative Study of Spillover Effect ω and an Analysis of its Microscopic Mechanism

ω represents the influence of R&D sector on economic growth through production sector, that is, the measurement of spillover effect of R&D sector.

We conclude that both the spillover effect of the basic R&D sector and the applied R&D sector can significantly promote economic growth. The achievements of basic R&D mainly include invention patents, scientific papers, academic monographs, etc. Although China's invention patents are less innovative and less enforceable, they are still improvements on existing technologies. Once some patented technologies that meet the needs of the Chinese market are used in production, they can improve productivity, save production costs and increase economic benefits. Papers and monographs are the crystallization of knowledge; they contain new ideas and new methods that can improve the management level of enterprises and the professional quality of employees, enhance the absorption capacity of enterprises, and ultimately increase the output. Yang also believes that without basic R&D, economic growth will be short-lived. [23] The economic benefits of the applied R&D

sector are extremely high. In 1991, the sales revenue from new products was 118.6 billion, and in 2014, the sales revenue was 1,236 billion, increasing by more than 100 times. Its contribution to the economy increased from 5.3% in 1991 to 19.2% in 2014. On the one hand, the production sector is an important starting point for the development of the applied R&D sector. The economic effect of the applied R&D sector cannot be achieved without the contribution of the traditional production sector. The rapid development of the economic benefits of the applied R&D sector will inevitably lead to the improvement of the economic benefits of the traditional sector. On the other hand, the economic effect of the applied R&D sector leads to the technical upgrading and progress of the production sector, thus improving the productivity of the production sector and promoting economic growth.

5.2 Comparative Study of σ and an Analysis of Its Microscopic Mechanism

σ represents the relative level of marginal return of factors between R&D sector and production sector.

$\sigma = 0.841$ indicates that the marginal return of factors of the basic R&D sector is lower than that of the production sector. The reasons for this are: first, most basic R&D cannot be monetized. Basic R&D mainly focuses on patents, monographs and papers. According to the *China Statistical Year book*, the number of domestic patent authorization reached 1.19 million in 2014 (Figure 3), ranking first in the world. Chinese authors published a total of 263,500 papers, ranking second in the world for the sixth consecutive year. China has rich achievements in the basic R&D sector, but these achievements are not directly related to production. The market cannot price and monetize them, and they cannot be included in the GDP. Therefore, in the basic R&D sector, the marginal return of input factors is lower than that of the production sector. Second, the commercialization rate of basic R&D achievements is low. According to the statistical data of the *Intellectual Property Report of Chinese Colleges and Universities* released by the Ministry of Education in 2015, despite the high number of patent applications, the average patent conversion rate of colleges and universities is only 5%, with a low market utilization rate and poor economic benefits. Third, patents last a short time. Generally speaking, the longer the patent is maintained, the greater will be the economic benefits and the market value. According to *The 2014 Annual Report on Valid Patents in China*, among the domestic effective invention patents, 49.2% are maintained for less than 5 years, and only 7.6% are valid for more than 10 years, while the proportion abroad reaches 32.8%. Therefore, in practice, we should introduce an appropriate evaluation system to include these non-monetary achievements within the scope of performance appraisal. At the same time, we should introduce an appropriate market mechanism and guide the research direction of basic research with the power of the "invisible hand". The market will allocate resources to the basic R&D sector with higher efficiency. Finally, it is necessary to strengthen the ties between industry, education and research, promote patented products, implement commercialization and improve economic efficiency.

$\sigma = 3.254$ indicates that the marginal return of factors of the applied R&D sector is higher than that of the production sector. The main outcome of the applied R&D sector is new products. New products are those products manufactured with new technology and new ideas, or products with obvious improvements in structure, material, process and other aspects, thus significantly expanding the scope of use and improving the product performance. From the perspective of demand, new products can directly or better meet people's different levels of material and personal needs and provide huge economic potential. From the perspective of supply, new products can improve the competitiveness and economic benefits of enterprises, which are fundamental to their survival and development. It can be seen that new products have extremely high economic returns and are an important driving force of China's economic growth. We should vigorously develop and introduce new products to meet social needs and promote economic development.

5.3 Comparative Study of γ and an Analysis of its Microscopic Mechanism

γ represents the impact of knowledge stock on innovation. No matter the basic R&D sector or the applied R&D sector, the empirical results are not significant. This means that the existing knowledge stock in China does not play a significant role in promoting innovation. This view is consistent with the basic hypothesis of Arrow's knowledge production function. Meanwhile, Wu found that the knowledge production of the basic R&D sector is related to labor input only, and has nothing to do with other input. [24] The existing knowledge stock in China does not play a significant role in promoting innovation for the following reasons: first, the core technical knowledge is relatively deficient and backward, which cannot promote R&D and the transformation of high-tech achievements. Although China's independent innovation input has been ever-increasing, its independent R&D capability is still weak, and the key technologies are still in the hands of developed countries. Most of the high-tech products that Chinese enterprises are invited to support are produced to take advantage of China's cheap labor force, and the level of technology is very low. [25] Second, the amount of research and development output is large, but the level of technology is low. According to the *Report on the Development of Intellectual Property in China in 2015*, China ranks first in the world for the number of patents granted. Among them, utility model patents and design patents account for 49.5% and 24.8% of the total number of effective patents in China, while the proportion of relatively innovative invention patents is very small (Figure 4). Therefore, the increase in the number of patents only means a low level of repetition, which does little to promote the production of knowledge with higher innovation requirements.

It was also found that the knowledge stock of the applied R&D sector has a spillover effect, while the knowledge stock of the basic R&D sector has a drag-out effect. The possible reason is that the innovation of the applied R&D sector has a higher market value and can encourage more innovation. On the contrary, the economic benefits of the basic R&D sector are poor, and they are basically maintained by state funds and subsidies which are not enough to drive innovation. At the same time, this is inconsistent with the rapid growth of the number of papers and patents in China. The possible reason is the existence of a large

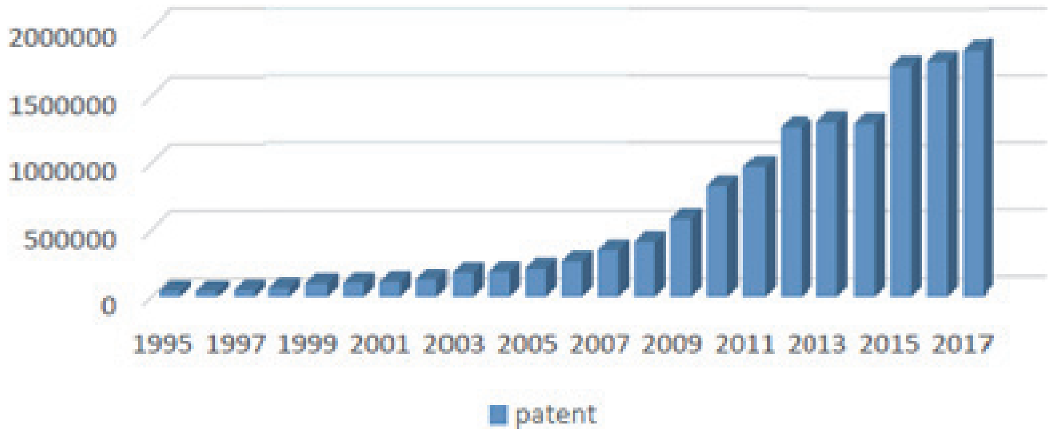

Figure 3 Patent authorizations between 1995 and 2017.

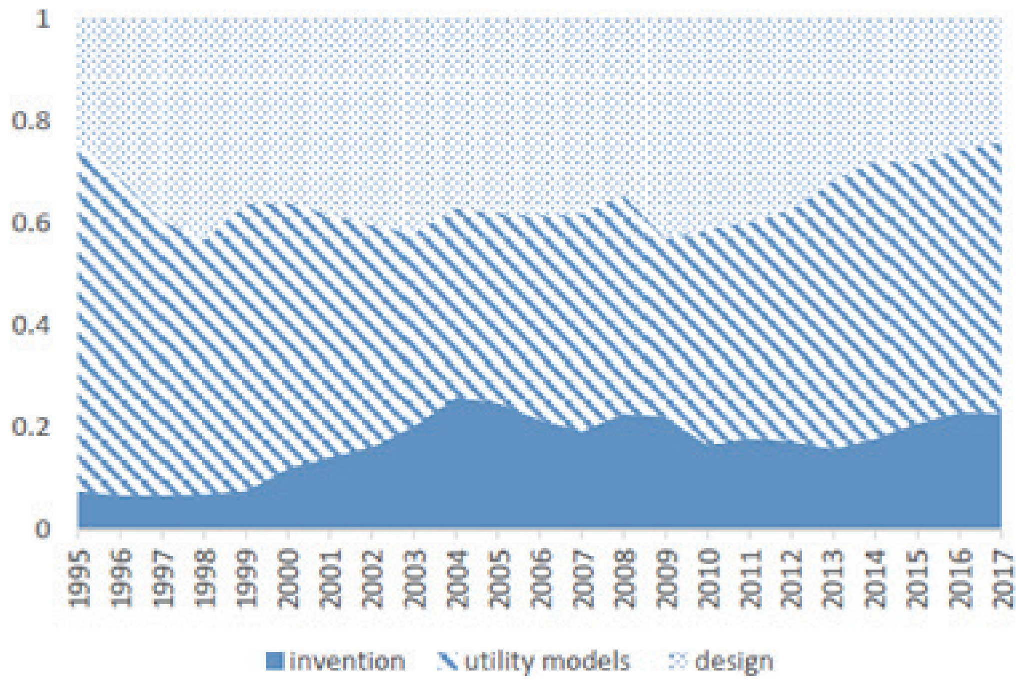

Figure 4 The rate of invention patent, utility models patent and design patent.

number of "garbage papers" and "garbage patents". Despite their huge number and rapid growth, they lack innovation, and crowd out and waste a large amount of public resources.

6. CONCLUSIONS AND IMPLICATIONS

This study improves the dynamic field model according to the characteristics of knowledge production, and separates the direct effect and spillover effect of R&D, so as to facilitate the accurate measurement of the spillover effect. According to the diversity of R&D outputs, we divided the R&D sector into basic R&D and applied R&D, and measured the spillover effects in both R&D sectors. The conclusions of this paper are as follows: for the model, the spillover effect of R&D promotes economic growth; the empirical studies show that the spillover effect of basic R&D and applied R&D significantly promotes economic growth. The marginal return of factors of the basic R&D sector is lower than that of the production sector, while the applied R&D sector's is higher than that of the production sector. Currently in China, the knowledge stock does not play a significant role in promoting innovation. To be specific, the knowledge stock of applied R&D has a spillover effect, while the knowledge stock of basic R&D has a drag-out effect.

In order to solve the problems in the R&D field in China, we put forward the following suggestions: first, we should introduce an appropriate R&D quality assessment system and achievement evaluation system to solve the performance evaluation problem of R&D achievements and improve the related patent reward system. Second, we should introduce a market mechanism to carry out supply-side reform on R&D achievements, ensure the rational allocation of R&D resources, improve the economic benefits of R&D output, and guide the research direction. Third, on the one hand, we should accelerate the introduction and mastering of the core of frontier technology. On the other hand, we should strengthen the combination of independent development, commercialization of research results and industry-university-research, improve the market conversion rate and market utilization rate of research and development results, and increase economic benefits.

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