Research Article

Optimization Analysis for Innovative Inputs under the Objective Discrepancy between Government and Enterprise

Wu Kai and Zhang Huiying

1College of Management and Economics, Tianjin University, Tianjin 300072, China
2School of Economic and Management, Tianjin University of Science and Technology, Tianjin 300222, China

Correspondence should be addressed to Wu Kai; laokaino1@163.com

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1. Introduction

Industrialized countries have tried to foster innovation for many years. Guiding enterprises innovation through fiscal and tax policies is an important means to seek leading position in innovation and technological advantages [1]. Governments therefore set up public support programs such as R&D subsidies, subsidized loans, and R&D tax credits. Input-driven policy is typically designed to support R&D and contribute to the enhancement of innovation competences in individual firms [2] because they drive technological change by bringing radically new innovations to market [3]. Under such background, China has developed a set of national innovation policies, such as the Outline of the National Medium and Long term Science and Technology Development Plan, the National High tech Research and Development Plan (863 Plan), and the National Key Basic Research and Development Plan (973 Plan). In America, the Small Business Innovation Research (SBIR) was established under the Small Business Innovation Development Act of 1982, which was a set-aside program for domestic small business to engage in R&D activities. All across Europe, scientific institutions and innovative companies face a challenging new research framework: HORIZON 2020, which has led to a strong focus on the implementation of research and innovation within European societies. Summarizing the policies of these countries or regions, it can be seen that the government’s guidance on innovation attaches importance to R&D activities. From innovation project application, fund expenditure, project evaluation, and so on, it emphasizes “focusing on supporting strategic, cutting-edge, and forward-looking high-tech R&D activities related to long-term national development and national security, and preventing decentralized use.” At the same time, there exists a danger of these large public investments descending into a “subsidy race,” and as a result,
science and technology ecosystems could be damaged irreparably if enterprises are attracted by generous subsidies offered elsewhere and uproot their operations [4].

Because the innovation targets of the government and enterprises are not completely consistent, the enterprises innovation under the guidance of the government also has market failure. From the perspective of the government, the targets are to promote economic development and realize social benefits. Scientific and technological progresses are the decisive factors to ensure sustainable economic growth; therefore, subsidies will be designated for R&D to form knowledge accumulation and technology upgrading. Different from government’s concern about social benefits, enterprises are the main body of innovative activities, with the target of maximizing their own benefits. The innovative activities of enterprises are to obtain benefits through market. In order to maximize the enterprises benefits, resources are invested in R&D, transformation, and other businesses in a balanced manner, rather than a single R&D. Such discrepancy results in less R&D investment from enterprises, while more R&D investment from government subsidies leads to imbalance in the allocation of innovation resource.

For solving the mismatched allocation of innovative inputs between government and enterprises, it is necessary to regulate the government guidance, balance social benefits, and enterprises benefits and especially give consideration to enterprises benefits. In China, where the local environment for innovation is vastly heterogeneous, it is important for the government to consider differences, ensuring policies differentiation [5]. How to implement precise subsidies is an urgent problem. At the microlevel of enterprises innovation, this paper analyzes the allocation of innovative inputs to improve the subsidies efficiency. The main works are as follows: (1) based on the existing research results, it constructs two-stage innovation benefit model about R&D and transformation. Under the condition of limited innovation resources, it allocates innovative inputs between R&D and transformation according to the principle of equal marginal revenue. (2) Since innovation has invested from a single enterprises input to a double inputs of government and enterprises, the government pays attention to social benefits, while the enterprises care about their own benefits. The discrepancy between government and enterprises makes the allocation of innovation input inconsistent. Based on the Static Game of Complete Information Theory, the “iterated elimination of strictly dominated strategy” method is adopted to achieve the Nash equilibrium of innovative inputs between the government and enterprises. (3) We use computer program to simulate the allocation of innovative inputs. From the perspectives of social benefits and enterprises benefits, the simulation compares with the two popular government subsidy modes and analyzes the applicable conditions and the advantages of achieving Nash equilibrium of innovative inputs. This paper proposes an allocation scheme of innovative inputs at the microlevel to eliminate the hidden trouble of innovative resource mismatch before the implementation of enterprises R&D activities. The innovative inputs to achieve Nash equilibrium are a precise government subsidy mode, which conducts the resource allocation combined with government guidance and market-oriented operation.

2. Literature Review

Under different economic backgrounds, scholars have formed theoretical basis for the enterprises innovation with government guidance, such as the Theory of Endogenous Growth and National System of Innovation. The Theory of Endogenous Growth was gradually put forward in the 1980s to describe macroeconomic development. Romer, one of the representative scholars, introduced four elements including capital, labor force, human capital, and knowledge into the endogenous economic growth model, in which knowledge is the driving force of economic growth [6]. Schultz added the variable of human capital in Cobb Douglas production function and observed that human capital not only affected individual productivity but also improved the productivity of society [7]. The Theory of Endogenous Growth and subsequent empirical studies showed that technological progress was the endogenous factor of sustainable economic growth, and R&D activities were the source of technological progress. However, there was market failure in the R&D activities led by enterprises, and the national economic development needs to be guided by government policies. Under such backgrounds, on the basis of inheriting innovation theory, National System of Innovation, represented by Christopher Freeman and Richard R. Nelson, proposed that technological innovation was not only enterprises activities but also be driven by the national innovation system, which affected the allocation and efficiency of innovation resources [8, 9].

With the above theoretical backgrounds, this paper involves two topics including the policies effect of government subsidies and the allocation of innovation resources. The two topics are so interrelated that subsidy policies regulate the allocation of innovation resources, which reflects the effectiveness of subsidy policies. On the one hand, the policies effects of government subsidies on innovation are controversial, with both positive and negative effects. Based on the fact that negative effects occur frequently, it is necessary to re-examine subsidy policies from the perspective of innovative inputs. On the other hand, innovative inputs belong to the allocation of resources, involving the R&D capital, scientific and technological talents, and other elements. At the same time, the allocation of innovation resources has its particularity. The high cost, high risk, and the spillover of R&D lead to market failure, so the R&D investment by enterprises is low. Subsidies, as innovative inputs other than enterprises, encourage enterprises to make innovation decisions. It is necessary to review the allocation of innovation resources under government subsidies.

2.1. Negative Effects Caused by Government Subsidies. According to the innovation performance under the government subsidies, the effect of subsidies is controversial in existing literature, including three types of conclusions: the
incentive performance of promoting innovation, the negative performance of inhibiting innovation, and the mixed performance of “inverted U” [10, 11] or “double-edged sword” [12]. In the negative effects, it is found that subsidies lead to mismatch in the allocation of innovation resources.

One consequence of the mismatch is crowding out effect, for enterprises to reduce their own R&D investment after receiving subsidies. The higher subsidy level has a crowding out effect on the R&D investment, which is largely attributable to the managerial myopia of enterprises [10]. Based on dataset of Chinese electronic manufacturing industry, Empirical evidence confirms that it will inhibit innovation when there are too excessive subsidies [13]. With the increasing of government subsidies, the crowding in effect weakens gradually. Some scholars further revealed the influencing factors. When considering enterprises ownership, scale, industry and regional factors, and so on, government subsidies have a significant negative effect on state-owned enterprises and large enterprises [14]. Moreover, some findings indicated that the effect of subsidies is highly heterogeneous across different industry [15].

If dividing enterprises innovation into substantive innovation and strategic innovation [16], another consequence of the mismatch is strategic R&D behavior. Enterprises R&D are no longer market-oriented but cater to government preferences. Although the number of patent applications and scientific citation index (SCI) has increased gradually, enterprises R&D emphasize quantity over quality so much, that they ignore the transformation of R&D achievements in the market. Using Korean pharmaceutical industry data, the empirical evidence that the R&D subsidy program stimulated the biotechnology venture firms to expand their new product R&D activities is found to be rather weak [17]. Plagiarism, falsification, and fabrication have become a significant problem, so this behavior has led to a tendency to seek quick success and instant benefit [18]. If the crowding out subsidies can be applied to other economic fields, it can make the best use of it while strategic R&D is waste of resources. Strategic R&D not only affects economic benefits but also misleads literature conclusions. Some scholars take patents as dependent variable to verify the subsidies effect, but these R&D achievements have not been tested by the market and cannot be converted into social benefits through commercial operation. The findings overall are ambivalent, and the existing literature as a whole is subject to the criticism that the investigators envisage is not adequately specified [19].

The effect of subsidies on enterprises innovation depends not only on the amount of subsidies but also on the rational allocation of innovation resources. The above literatures reveal the negative effects caused by resource mismatch. The reason for the mismatch is the imbalance of innovative inputs under the guidance of the government subsidies. Innovation is associated with uncertainty and risks [20, 21], and at the same time, the knowledge generated by R&D activities has the attribute of public goods [22], and such characteristics determine that the allocation of innovation resources is different from the allocation of resources in the production field. The chronological alignment of innovation includes elementary R&D, the preparatory phase of production, production, marketing, and final sale [23], and therefore, resource allocation can not only emphasizes R&D activities. Government subsidies should be tailored to actual situations, combining conditions of enterprises to formulate schemes. It is necessary to implement precise and differentiated subsidy policies at the microlevel of innovation projects.

2.2. The Allocation of Innovation Resource. With further understanding of innovation, studies about the allocation of innovation resource have been accumulated. It has been gradually realized that innovation is not only R&D investment but also the allocation, integration, and reuse of innovation resources. Innovation resources performance is an important driver of global competitiveness of nations [8]. By constructing a performance evaluation system for the allocation of innovation resources, it was found that there were obvious disparities in the ability and efficiency in various regions [9]. For example, investment in knowledge-based capital (KBC) has implications for innovation and productivity growth; however, the returns to investing in KBC differ significantly across countries [24]. On the whole, the efficiency of innovation resources among different countries, and among different regions in a same country, as well as among different industries in a same region, shows obvious heterogeneity [25, 26]. In China, there are obvious spatial autocorrelation agglomeration characteristics of regional innovation output and R&D inputs [26]. The performance of innovation resource in industrial enterprises had a different spatial distribution, with high in eastern and central region and low in western region [8, 27].

In addition to the disparities among different regions and industries, another characteristic of innovation resource allocation is low efficiency. Although the overall efficiency of the innovation resources increased, the scale efficiency was relatively low [28]. For example, the empirical research shows that the efficiency of innovation resource allocation in the aerospace industry is generally at the lower middle level, and the efficiency improvement in recent years is not obvious [29]. One reason for the low efficiency is the mismatched allocation, which can lower aggregate total factor productivity (TFP) [30]. Another reason is the low transformation of innovation achievements, for that the optimization of overall efficiency is restricted by lower efficiency of innovation achievement transformation [31].

The above literatures show that the allocation of innovation resources is disparate and inefficient among regions. Therefore, the national innovation strategy is not only to provide subsidies but also to improve the efficiency of subsidies and rationally allocate innovation resources. However, previous studies of innovation policies show that there is a mismatch between the underlying assumptions of these policies and the reality of how firms involved in innovation operation [32]. Most of the subsidies are distributed to state-owned enterprises, but the state-owned enterprises have significantly lower R&D and productive
3.1. Theoretical Basis. Innovation is a process of converting creative ideas into products, services, or other business operations. Innovation is not an isolated activity but rather an entire process or even sequence of processes. With true innovation, every partial process should be successfully completed [36]. As a process, it should attend to the way in which innovation has been organized so that benefits can come to fruition; this includes an overall research process and a new product development process [37]. Joseph A Schumpeter pointed out that entrepreneurs innovate not just by figuring out how to use inventions but also by introducing new means of production, new products, and new forms of organization [38]. To review the basic concept of innovation, it is mainly to explain that innovation is not a technical concept but an economic concept. Innovation is strictly different from R&D, and it is to introduce technology into economic organizations to form new economic capabilities. The success of innovation must be tested by the market to bring about benefits and achieve sales revenue or profit growth. In the traditional linear model, innovation is represented by a pipeline of sequential processes, which starts at pure scientific research and ends with commercial applications. Berkhout et al. replace the traditional chain concept to describe the innovation regime by a circle of change including scientific insights, technological capabilities, product design and manufacturing, and markets [39]. According to the value chain theory, in order to obtain innovative benefits, it is necessary to have R&D investment and corresponding large-scale production, marketing, and other transformational investment. Through transformational investment, it can put new technologies, methods, and processes into practice to achieve benefits [40, 41]. According to the basic concept of innovation and the above related research, this paper divides innovative activities into two stages: R&D and market transformation.

R&D Functions: Griliches was the first scholar to propose a quantitative model of knowledge production to estimate returns to R&D [42]. Romer, a representative scholar of the New Economic Growth Theory, expressed knowledge production in the form of Cobb Douglas function [6]. Assuming that the enterprises’ knowledge stock is \( A_0 \) (all the description of parameters is shown in Table 1), the R&D inputs are mainly capital and technological talents, and the capital is used to purchase instruments, equipment, and laboratory. With reference to the above, we define the R&D function as \( A = A_0 K_t^xL_t^y + \epsilon, \epsilon \) is exogenous random variable, which obeys the law of normal distribution \( N(0, \sigma^2) \). After R&D stage, the expected value of new knowledge is \( E(A) = A_0 K_t^xL_t^y \).

**Lemma 1.** When the R&D budget and the price of inputs are determined, the inputs quantity of R&D stage are \( K_1 = (xL_1/u(x + y)), L_1 = (yU/v(x + y)), \) and the expected R&D output is \( E(A) = A_0 (x/u(x + y))^\gamma (y/v(x + y))^\gamma I_e^\gamma \).

**Proof.** When the R&D budget and the price of inputs are determined, the objective is to choose \( K_1 \) and \( L_1 \), so as to maximize \( E(A) \), the problem is described as follows:

\[
\begin{aligned}
\text{max} & \quad E(A) = A_0 K_t^xL_t^y \\
\text{s.t.} & \quad I_e = K_1u + L_1v
\end{aligned}
\]

Using Lagrange function

\[
f = A_0 K_t^xL_t^y - \lambda (K_1u + L_1v - I_e),
\]

then

\[
\begin{aligned}
\frac{\partial f}{\partial K_1} &= xA_0 K_t^{x-1}L_t^y - \lambda u = 0, \\
\frac{\partial f}{\partial L_1} &= yA_0 K_t^{x-1}L_t^{y-1} - \lambda v = 0, \\
\frac{\partial f}{\partial \lambda} &= K_1u + L_1v - I_e = 0.
\end{aligned}
\]

It can get a unique solution \( K_1 = (xL_1/u(x + y)) \), \( L_1 = (yU/v(x + y)) \).

Substituting \( K_1 \) and \( L_1 \) into \( E(A) \), it can get \( E(A) = A_0 (x/u(x + y))^\gamma (y/v(x + y))^\gamma I_e^\gamma \).
This completes the proof.

**Proposition 2.** If defining \( \varphi = (x/u(x + y))^t (y/v(x + y))^y \) and \( \alpha = x + y \), the expected R&D output from lemma 1 can be simplified as follows:

\[
E(A) = A_0 \varphi I_c^t,
\]

(2)

3.1.1. Transform Function. The technology and knowledge generated by R&D are transformed into productivity through production and operation activities to realize innovative benefits. The transformational benefits are expressed as \( R_c = AK_2L_2^t \). The new knowledge \( A \) generated in the R&D stage becomes the transformational input.

**Lemma 3.** When the transformational budget and the price of inputs are determined, the inputs quantity of transformational stage are \( K_2 = (sP_c/u(s + t)), \quad L_2 = (tP_c/w(s + t)) \), and the transformational benefits is \( R_c = A(s/u(s + t))^t (t/w(s + t))^y P_c^t \).

The main idea of proof is the same as Lemma 1.

**Proposition 4.** If defining \( \varphi = (s/u(s + t))^t (t/w(s + t))^y \) and \( \beta = s + t \), the transformational benefits from lemma 2 can be simplified as follows:

\[
R_c = A \varphi P_c^\beta.
\]

(3)

3.2. The Expected Innovative Benefits Function. R&D and transformation complement each other and work together to generate innovative benefits. Based on the above analysis, the R&D function (2) is substituted into the transformation function equation (2) to get the expected innovative benefits, as shown in the following equation:

\[
E(R_c) = A_0 \varphi \Phi I_c^t P_c^\beta.
\]

(4)

In the innovative planning stage, enterprises evaluate the innovative benefits and allocate budgets in R&D and transformation, referring to (4) to calculate the quantity of inputs according to the principle of equal marginal benefits.

**Lemma 5.** Under the condition of limited budget, the quantity of R&D inputs and transformational inputs is, respectively, \( I_c = (\alpha M_c / \alpha + \beta) \) and \( P_c = (\beta M_c / \alpha + \beta) \).

**Proof.** When the innovative budgets are determined, the objective is to choose \( I_c \) and \( P_c \), so as to maximize \( E(R_c) \), the problem is described as follows:

\[
\begin{align*}
\max \quad & E(R_c) = A_0 \varphi \Phi I_c^t P_c^\beta \\
\text{s.t.} \quad & M_c = I_c + P_c
\end{align*}
\]

Using Lagrange function

\[
f = A_0 \varphi \Phi I_c^t P_c^\beta - \lambda (I_c + P_c - M_c),
\]

then

\[
\begin{align*}
\frac{\partial f}{\partial I_c} = \alpha A_0 \varphi \Phi I_c^{t-1} P_c^\beta - \lambda &= 0, \\
\frac{\partial f}{\partial P_c} = \beta A_0 \varphi \Phi I_c^t P_c^{\beta-1} - \lambda &= 0, \\
\frac{\partial f}{\partial \lambda} = I_c + P_c - M_c &= 0.
\end{align*}
\]

(5)

It can get a unique solution \( I_c = (\alpha M_c / \alpha + \beta) \), \( P_c = (\beta M_c / \alpha + \beta) \).
This completes the proof.

Modern economic growth shows that R&D activities promote the generation of new technologies and knowledge, and technological progress and knowledge accumulations are the core of economic growth [43, 44]. The new knowledge generated by R&D has positive externalities through diffusion [45], which drives the technological upgrading of the industrial chain. The knowledge spillover also has an incentive effect on the technological upgrading of the competitive enterprises, making the social benefits of innovation greater than the enterprises' benefits [46]. In this paper, the social benefits of innovation are described as (6). Parameter $\gamma$ represents the sensitivity of social benefits to R&D inputs, $\gamma > \alpha$.

$$E(R_g) = A_0 \varphi I_p \beta.$$  \hfill (6)

3.3. Innovative Benefits Function under Government Subsidies. When the government subsidizes enterprises innovation, the social benefits and enterprises' benefits of innovation are shown in the following equation:

$$\begin{align*}
E(R_g) &= A_0 \varphi (I_g + I_e)^{\gamma} (P_g + P_e)^{\beta}, \\
E(R_e) &= A_0 \varphi (I_g + I_e)^{\gamma} (P_g + P_e)^{\beta}.
\end{align*}$$  \hfill (7)

The objectives of the government and enterprises are not completely consistent. The government pays attention to social benefits while the enterprises care about their own benefits. Government and enterprises allocate innovative inputs from the perspective of their benefits respectively, so the innovative inputs of both sides are not consistent.

**Lemma 6.** From the perspective of social benefits, the optimal R&D input $I_g^*$ and transformational input $P_g^*$ are shown in equation (6).

**Proof.** To maximize social benefits, the innovation optimization is described as follows:

$$\begin{align*}
\max E(R_g) &= A_0 \varphi (I_g + I_e)^{\gamma} (P_g + P_e)^{\beta}, \\
\text{s.t.} & I_g + P_g = M_g, I_e + P_e = M_e.
\end{align*}$$  \hfill (8)

Solving the above optimization, the government's expected innovative inputs are

$$\begin{align*}
I_g + I_e &= (\gamma (M_g + M_e) / (\gamma + \beta)) \\
P_g + P_e &= (\beta (M_g + M_e) / (\gamma + \beta)).
\end{align*}$$

Since the government cannot directly interfere with the enterprise inputs, the optimal R&D input $I_g^*$ and transformational input $P_g^*$ are shown in the following equation:

$$\begin{align*}
I_g^* &= \frac{\gamma (M_g + M_e)}{\gamma + \beta} - I_e, \\
P_g^* &= \frac{\beta (M_g + M_e)}{\gamma + \beta} - P_e.
\end{align*}$$  \hfill (9)

This completes the proof.

**Lemma 7.** From the perspective of enterprises benefits, the optimal R&D input $I_g^*$ and transformational input $P_g^*$ are shown in equation (7).

The main idea of proof is the same as Lemma 6.

$$\begin{align*}
I_g^* &= \frac{\alpha (M_g + M_e)}{\alpha + \beta} - I_g, \\
P_g^* &= \frac{\beta (M_g + M_e)}{\alpha + \beta} - P_g.
\end{align*}$$  \hfill (10)

From the above (9) and (10), it can be seen that the innovative inputs of government and enterprises are different. The problems faced by the government and enterprises are how to adjust the inputs to maximize their expected benefits, respectively. According to the process of policy issuance and enterprises subsidy application, the following part of the paper uses static games of complete information to solve the problem of the allocation of innovative inputs.

4. Innovative Inputs Achieving the Nash Equilibrium

According to the subsidies distribution process, the government first issues subsidy policy, indicating the amount, mode of subsidy, application conditions, and acceptance criteria after completion, etc. According to the subsidy policy requirements, the enterprises shall fill in the application statement, including technical basis, R&D progress, and expected benefits. During the whole process, the information of both sides is so complete, that the government and enterprises understand each other's objectives and budgets. The objective of the government is to maximize the social benefits, and the enterprises pursue the maximization of its own benefits. In this case, the solution of innovative inputs is consistent with the static game of complete information. The government and enterprises can reach a Nash equilibrium agreement that they both abide by to achieve a balanced inputs.

Based on the Static Game of Complete Information theory, the Nash equilibrium of innovative inputs can be achieved. According to (9), that is, the function of the government's optimal R&D inputs, draw a straight line $gg$, where the $Y$-axis is the government's R&D inputs, and the $X$-axis is the enterprises' R&D inputs. In turn, according to (10), the optimal R&D inputs line of the enterprises is $ee$. On the $Y$-axis, the intercept of line $gg$ is larger than that of line $ee$, as shown in Figure 1. Corresponding to Figure 1, $gg$ and $ee$ in Figure 2 represent the optimal transformational inputs of the government and enterprises, respectively, and the intercept of line $ee$ is larger than that of line $gg$.

Since subsidies and enterprises budgets are determined, the government and enterprises allocate R&D inputs and transformational inputs to achieve Nash equilibrium, which is divided into three configuration structures.
Theorem 8. When government subsidies and enterprises budgets reach condition \((M_g/M_e) \geq (y/\beta)\), innovative inputs tend to conform to government preference, and the configuration structure is \(I_g = (y(M_g + M_e)/\gamma + \beta), P_g = (\beta M_g - yM_e/\gamma + \beta), I_e = 0, P_e = M_e\).

4.1. Solution Idea. When \((M_g/M_e) \geq (y/\beta)\), it is equivalent to \(M_g \geq (y(M_g + M_e)/\gamma + \beta)\). According to the R&D inputs line in Figure 1, the above configuration structure can be verified by the method of “iterated elimination of strictly dominated strategy.”

(1) Enterprises R&D inputs will not exceed \([0, e']\), so this information means that for the government, \(I_e \in [a, g]\) is better than \(I_g \in [0, a]\). Therefore, the R&D inputs of enterprises and government are located in \(I_e \in [0, e], I_g \in [a, g]\), respectively.

(2) If the government R&D inputs conform to \(I_g \in [a, g]\), \(I_e \in [0, d]\) is better than \(I_g \in [d, e']\) on the X-axis for enterprises. Therefore, the R&D inputs of enterprises and government are located in \(I_e \in [0, d], I_g \in [a, g]\), respectively.

(3) If the enterprises R&D inputs conform to \(I_e \in [0, d]\), so this information means that for the government, \(I_g \in [f, g]\) is better than \(I_g \in [a, f]\). Therefore, the R&D inputs of enterprises and government are located in \(I_e \in [0, d], I_g \in [f, g]\), respectively.

(4) If the government R&D inputs are \(I_g \in [f, g]\), then the government R&D inputs have exceeded the enterprises’ optimal R&D inputs \((a(M_g + M_e)/a + \beta)\), so the enterprises choose R&D inputs \(I_e = 0\). In this case, the optimal government R&D inputs are point \(g\) in Figure 1, that is, \(I_g = y(M_g + M_e)/\gamma + \beta\).

Through the method of “iterated elimination of strictly dominated strategy,” the final R&D inputs portfolio is \((I_g = y(M_g + M_e)/\gamma + \beta, I_e = 0)\). The government’s remaining subsidies are used for transformational inputs \(P_g = M_g - I_g = (\beta M_g - yM_e/\gamma + \beta)\), while the enterprises will use all the budgets for transformational inputs \(P_e = M_e\).

According to the transformational inputs line in Figure 2, the above conclusions can also be verified. The government subsidies \(M_g \geq (y(M_g + M_e)/\gamma + \beta)\) correspond to Point A above the point \(g\) on the Y-axis as shown in Figure 1. \(M_g \geq (y(M_g + M_e)/\gamma + \beta)\) is equivalent to \(M_e \leq (\beta(M_g + M_e)/\beta + \gamma)\) and corresponds to the \([0, g]\) segment of the Y-axis in Figure 2. Part A in Figures 1 and 2 is consistent. If the enterprises’ budgets are \(M_e = h\), all the enterprises inputs will not exceed point \(h\) on the Y-axis. At this time, the optimal government transformational inputs are \(h\) that are \(P_g = (\beta(M_g + M_e)/\gamma + \beta) - M_e = (\beta M_g - yM_e/\beta + \gamma)\), and the government remaining subsidies are used for R&D inputs \(I_g = M_g - (\beta M_g - yM_e/\beta + \gamma) = (y(M_g + M_e)/\beta + \gamma)\).

Will the enterprises use all the budgets to transform inputs? When the government transformational inputs are \(h\), the optimal transformational inputs of the enterprises are point \(i\) on the Y-axis of Figure 2. Because the enterprises budgets are insufficient, even if all the budgets are used for transformation, it cannot meet point \(i\). At this time, the enterprises will not use the limited budgets for R&D inputs.

From the above analysis, the government provides all R&D inputs and uses the remaining subsidies for transformation. The enterprises will use all budgets for transformation. The sum of R&D inputs is \(I_g + I_e = (y(M_g + M_e)/\gamma + \beta)\), and the sum of transformational inputs is \(P_g + P_e = (\beta(M_g + M_e)/\gamma + \beta)\). Innovative inputs tend to conform to government preference, while from the perspective of enterprises, transformational inputs are relatively insufficient. This configuration structure is determined by \(y\) and \(\beta\). The more \(y\) is, the more R&D inputs are.

Theorem 8 shows that although the purpose of subsidies is to stimulate R&D, when the proportion of subsidies to enterprises budgets is large, it is inappropriate to use all subsidies for R&D. From the perspective of social benefits, a part of subsidies can be used to transformational inputs, which can achieve balanced resource allocation. When the subsidies remain unchanged, R&D inputs increase with more enterprises budgets. However, if the enterprises continue to increase budgets, which change the proportion.
of \((M_g/M_c) \geq (\gamma/\beta)\), it will enter into the second configuration structure.

**Theorem 9.** When government subsidies and enterprises budgets satisfy condition \((\alpha/\beta) \leq (M_g/M_c) < (\gamma/\beta)\), innovative inputs tend to conform to government preference and enterprises preference, and the configuration structure is \(I_g = M_g, P_g = 0, I_e = 0, P_e = M_c\).

4.2. Solution Idea. When \((\alpha/\beta) \leq (M_g/M_c) < (\gamma/\beta)\), it is equivalent to \((\alpha(M_g + M_c)/\alpha + \beta) \leq M_g < (\gamma(M_g + M_c)/\gamma + \beta)\). The subsidies are less than the government’s expected R&D inputs but more than the enterprises’ expected R&D inputs. This situation corresponds to Part B between point e and point g on the Y-axis of Figure 1. From the perspective of government, even if all subsidies are used for R&D, it cannot reach the expected R&D inputs, so the limited subsidies will not be used for transformation. From the perspective of enterprises, the government’s R&D inputs have exceeded expectations, and it is the best choice for enterprises to use all budgets for transformation. \((\alpha(M_g + M_c)/\alpha + \beta) \leq M_g < (\gamma(M_g + M_c)/\gamma + \beta)\) is equivalent to \((\beta(M_g + M_c)/\beta + \gamma) < M_g < (\beta(M_c + M_c)/\beta + \alpha)\); therefore, Part B in Figure 1 corresponds to Part B in Figure 2. The enterprises budgets are less than the expected transformational inputs but more than the expected transformational inputs of government. The enterprises will use the limited budgets for transformation, and the government will use subsidies for R&D. The same conclusion can be drawn from the R&D line in Figure 1 and the transformation line in Figure 2.

In this case, the total R&D inputs are \(I_g + I_e = M_g\), the total transformational inputs are \(P_g + P_e = M_c\), and the innovative inputs are between the government preference and the enterprises preference. From the perspective of the government, R&D inputs are relatively less. If the government increases subsidies at this time, it will continue to be used for transformation. However, if the enterprises continue to increase budgets, which change the proportion of \((M_g/M_c) < (\alpha/\beta)\), it will enter into the third configuration structure.

**Theorem 10.** When government subsidies and enterprises budgets satisfy condition \((M_g/M_c) < (\alpha/\beta)\), innovative inputs tend to conform to government preference, and the configuration structure is \(I_g = M_g, P_g = 0, I_e = (\alpha M_e - \beta M_g)/\alpha + \beta, P_e = (\beta M_c - \beta M_g)/\alpha + \beta\).

4.3. Solution Idea. When \((M_g/M_c) < (\alpha/\beta)\), it is equivalent to \(M_g < (\alpha(M_g + M_c)/\alpha + \beta)\). Subsidies are less than the R&D inputs expected by the government and also less than the R&D inputs expected by enterprises. This corresponds to part C between point 0 and point e on the Y-axis of Figure 1. When \(M_g = a\), the government’s R&D inputs will not exceed point a. At this time, the enterprises’ corresponding R&D inputs are point d, that is, \(I_e = (\alpha(M_g + M_c)/\alpha + \beta) - M_g = (\alpha M_e - \beta M_g)/\alpha + \beta\), and the enterprises’ remaining budgets are used for transformation. Will the government use all the subsidies for R&D inputs? When the enterprises R&D inputs are \(d\), the optimal R&D inputs of the government are point f on the Y-axis. Because the government subsidies are insufficient, even if all the subsidies are used for R&D, it cannot satisfy point f. At this time, the government will not use the limited subsidies for transformational inputs. \(M_g < (\alpha(M_g + M_c)/\alpha + \beta)\) is equivalent to \(M_g > (\beta(M_g + M_c)/\alpha + \beta)\). Part C in Figure 1 corresponds to Part C in Figure 2. Enterprises use the remaining budgets for R&D on the premise of satisfying the transformational inputs. The same conclusion can be drawn from the R&D line in Figure 1 and the transformation line in Figure 2.

In this case, comparing with the enterprises budgets, government subsidies are insufficient. The government will use all subsidies for R&D. The enterprises use part of the budgets for R&D to make up for insufficient subsidies and use the other part of the budgets for transformation. The sum of R&D inputs is \(I_g + I_e = M_g + (\alpha M_e - \beta M_g)/\alpha + \beta\), and the sum of transformational inputs is \(P_g + P_e = (\beta(M_g + M_c)/\alpha + \beta)\). Innovative inputs tend to conform to enterprises preference, while from the perspective of government, R&D inputs are relatively insufficient. This configuration structure is determined by \(\alpha\) and \(\beta\). The more \(\alpha\) is, the more R&D inputs are.

The innovative inputs allocation to achieve Nash equilibrium is a precise subsidy policy, which is to allocate resources according to the principle of maximizing social benefits and enterprises benefits. The configuration structures are oriented by innovative benefits. It not only gives play to the guidance of subsidies on enterprises innovation but also takes in account the independent choice of enterprises.

5. Numerical Simulation and Discussion

The above analysis shows that the allocation of innovative inputs needs to adopt the corresponding configuration structure according to the proportion of government subsidies to enterprises budgets. The computer simulation can visually display innovative inputs. The simulation program is developed with Java language, and the simulation data is stored in the Access Database. The innovative benefits have a decreasing scale effect on the inputs [47, 48], so the simulation parameter is set as \(\alpha + \beta \leq 1\). From the social perspective, referring to the Theory of Endogenous Growth, economic growth comes from scientific and technological progress [6], so the simulation parameter is set as \(\gamma + \beta > 1\).

5.1. Example of Configuration Structures to Achieve Nash Equilibrium. Figure 3 shows the configuration structure under different enterprises budgets when the subsidies are unchanged. When \(M_g = 0\), the government invests in innovation independently and allocates subsidies according to the principle of maximizing social benefits; at this time, \(I_g = (\gamma M_g/\gamma + \beta)\) and \(P_g = (\beta M_g/\gamma + \beta)\). In the simulation,
assuming $\beta$ is greater than $\gamma$, so the transformational inputs are slightly larger than the R&D inputs. If the enterprises budgets are in the part A, and that is, $(M_g/M_e) < (\gamma/\beta)$, the configuration structure complies with Theorem 8. In this range, as the enterprises budgets increase, the enterprises will use all the budgets for transformation, and the government will gradually decrease the transformational inputs for increasing R&D inputs. For each additional unit of the enterprises budget, R&D inputs increase by $(\gamma/\beta)$ and transformational inputs increase by $(\beta/\alpha + \beta)$. If the enterprises budgets are increased to part B, it is equivalent to $(\alpha/\beta) \leq (M_g/M_e) < (\gamma/\beta)$, and the configuration structure complies with Theorem 9. Figure 3 assumes that the government subsidies are unchanged, so at this range, all subsidies are used for R&D, and R&D inputs present a straight line. Every additional unit of the enterprises budgets are used for transformation. If the enterprises budgets are increased to part C, it is equivalent to $(M_g/M_e) < (\alpha/\beta)$, and the configuration structure conforms to Theorem 10. All subsidies are used for R&D, and the enterprises budgets are invested in R&D and transformation in proportion. For each additional unit of the enterprises budget, R&D inputs increase by $(\alpha/\alpha + \beta)$, and transformational inputs increase by $(\beta/\alpha + \beta)$.

Figure 4 shows the configuration structure under different subsidies when the enterprises budgets are unchanged. The configuration structure of part A in Figures 1–4 is the same, so are part B and part C. Figure 4 shows the crowding out effect of subsidies on enterprises R&D inputs. When there is no subsidy, i.e., the X-axis origin, the enterprises allocate the budgets according to the principle of maximizing their own benefits $I_e = (\alpha M_g/\alpha + \beta/P_e) = (\beta M_g/\alpha + \beta)$. If the subsidies are within part C, it is equivalent to $(M_g/M_e) < (\alpha/\beta)$. For each additional unit of subsidy, the enterprises’ R&D inputs will decrease by $(\beta/\alpha + \beta)$, and the reduced R&D inputs will be used for transformation. If the subsidies are increased to $(M_g/M_e) < (\alpha/\beta)$, that is, part B and part A in Figure 4, the R&D inputs of enterprises are all crowded out for transformation.

5.2. Comparative Analysis of Three Subsidies Modes. The configuration structure to achieve Nash equilibrium is derived from theoretical analysis. Whether it is feasible in practice needs further analysis. There are two allocating modes in the existing government subsidies. One is that the government designates subsidies for R&D inputs, such as the “Technological Innovation Fund for Small and Medium sized Technological Enterprises,” which stipulates that subsidies are used for research, development, and pilot scale test of technological innovation. The other is that the government does not designate the subsidies for R&D or transformation but depending on the enterprises to fill in the budget according to the subsidies policy. Some special innovation projects adopt this mode such as “intelligent manufacturing integrated standardization and new application project.” Although the government does not designate the use of subsidies, it will formulate evaluation criteria in advance and organize professional institutions to audit that subsidies are used for project implementation. Therefore, the computer program simulates three subsidy modes. The first is that government led the subsidies for R&D. The second is that enterprises led the subsidies for R&D or transformation, aiming at maximizing their own benefits according to Lemma (3). Based on the analysis of Theorems 8–10, the third is achieving Nash equilibrium between the government and enterprises to adopt the corresponding configuration structure according to the proportion of government subsidies to enterprises budgets.

In simulation 1, the proportion of government subsidies to enterprises budgets reaches $(M_g/M_e) < (\alpha/\beta)$, and the innovative benefits are shown in Figure 5. In terms of social benefits, achieving Nash equilibrium between government and enterprises is the largest, as shown in part c. At the initial stage on the Y-axis, social benefits under the government led are greater than the enterprises led. However, when subsidies increase to a certain extent along the Y-axis, social benefits under the enterprises led exceed the government led. The growth rate of social benefits among three modes is
different, which is in the order of part $c < part b < part a$. In terms of enterprises benefits, the enterprises led is always the largest as shown in part $e$, and the government led is always the least as shown in part $d$. The enterprises benefits are in the order of part $e < part f < part d$. Simulation 1 shows that if the subsidies are designated for R&D, when the subsidies...
exceed a certain proportion, both social benefits and enterprises benefits are the least.

In simulation 2, the proportion of government subsidies to enterprises budgets reaches \((a/\beta) \leq (M_g/M_e) < (\gamma/\beta)\), and the innovative benefits are shown in Figure 6. The benefits under government led and the benefits under achieving Nash equilibrium have the same result, the social benefits are shown in part a, and the enterprises benefits are shown in part c. In accordance with Theorem 9, both modes use subsidies for R&D and enterprises budgets for transformation. The mode under enterprises led has the least social benefits as shown in part b; however, it has the largest enterprises benefits as shown in part d.

In simulation 3, the proportion of government subsidies to enterprises budgets reaches \((M_g/M_e) < (a/\beta)\). In this case, the innovative benefits under three subsidies modes are the same, so for simplicity, the figure has been omitted. Because the proportion of government subsidies is few, no matter which mode is adopted, enterprises can adjust innovative inputs to maximize their own benefits.

Comparing the above simulation experiments, when the proportion of government subsidies is relatively few, within \((M_g/M_e) < (a/\beta)\), subsidies mode does not affect the innovative benefits. When the proportion of government subsidies is moderate \((a/\beta) \leq (M_g/M_e) < (\gamma/\beta)\), both the innovative inputs under government led and the innovative inputs under achieving Nash equilibrium are beneficial to social benefits. When the proportion of government subsidies is relatively large, within \((M_g/M_e) \geq (\gamma/\beta)\), innovative inputs under achieving Nash equilibrium are beneficial to social benefits, and innovative inputs under enterprises led are beneficial to enterprises benefits. Under government led, subsidies designated for R&D may cause dual losses of social benefits and enterprises benefits.

6. Conclusions

With government subsidies, innovation is changed from single enterprises investment to joint investments of government and enterprises. Based on the Static Game of Complete Information theory, the “iterated elimination of strictly dominated strategy” method is adopted to achieve the Nash equilibrium of innovative inputs between the government and enterprises. It is a precise subsidy mode to inhibit mismatch of innovative inputs from the microlevel. The main conclusions are as follows:

(1) There are three kinds of resource allocation structure in the way of achieving Nash equilibrium. When the proportion of government subsidies to enterprises budgets reaches \((M_g/M_e) \geq (\gamma/\beta)\), innovative inputs tend to conform to government preference. When the proportion of subsidies to enterprises budgets is moderate, within \((a/\beta) \leq (M_g/M_e) < (\gamma/\beta)\), innovative inputs tend to between government preference and enterprises preference. When the proportion of government subsidies reaches \((M_g/M_e) < (a/\beta)\), innovative inputs tend to conform to enterprises preference. Both the sensitivity of innovative benefits to R&D inputs and the sensitivity of innovative benefits to transformational inputs determine the allocation structure. If the social sensitivity of innovative benefits to R&D inputs is far more than enterprises’ sensitivity to R&D inputs, R&D inputs from enterprise are insufficient. It points out the direction for government subsidies. To increase financial subsidies for national defense and public infrastructure, innovative projects can meet with necessary R&D inputs and achieve necessary social benefits.

(2) Achieving Nash equilibrium in innovative inputs is a precise subsidy mode, which not only realizes the guidance of subsidies on innovation but also takes into account the enterprises benefits. In order to maximize their own benefits, enterprises should allocate innovative inputs according to the principle of equal marginal benefits. If the subsidies are designated for R&D inputs, the enterprises reduce its R&D inputs for other stage of innovation, such crowding out is an inevitable choice for the enterprises to seek their own benefits. Damrich et al. confirmed that the crowding out would occur when government deprives the private sector of the means to exploit new knowledge [49]. From the perspective of resource allocation, this paper shows that additional subsidies used for R&D make the marginal benefits of R&D less than the marginal benefits of transformation. Enterprises reduce their R&D inputs, and the crowding out effect is an inevitable choice for enterprises to seek their own benefits.

(3) By comparing three subsidy modes, it makes clear the applicable conditions of precise subsidies to achieve Nash equilibrium. When the proportion of government subsidies to enterprises budget is relatively less, the subsidy mode does not affect innovative benefits. When the proportion of government subsidies to enterprises budget is relatively more, and subsidies are designated for R&D, it may cause dual losses of social benefits and enterprises benefits. Government subsidies reduce enterprises’ economic performance despite promoting indigenous innovation in the higher technology industries. If the subsidies are designated for R&D, when the subsidy exceeds a certain proportion, enterprises cannot reach the ideal resource allocation. If the inputs in one stage exceed the reasonable limit and disturb inputs proportion with other stages, it will inevitably distort the resources allocation and reduce the overall innovation efficiency. How to avoid such situation? Prokop et al. advocated that a suitable R&D subsidy mix enables avoiding misallocation [50]. This paper shows that rational allocation of innovative inputs can avoid inefficiency. By building information infrastructure, including information technology innovation and even digital innovation, government can enhance information transparency to facilitate rational allocation of
innovative inputs. Through the creation or adoption, and exploitation of an inherently unbounded, value-adding novelty (e.g., product, service, process, or business model) through the incorporation of digital technology [51], digital integration is conducive to improvements innovation performance. It has a significant effect on the improvement of strategic flexibility and dynamic capabilities [52]. Regarding the allocation of innovative resources, it promotes the decision-making between government and enterprises to be more scientific, reasonable, and effective and then improves the allocation of innovation resources.

By achieving the Nash equilibrium of innovative inputs, the government and enterprises can balance each other to maximize their respective benefits, which is of great practical significance to improve the efficiency of government subsidies and to mobilize the enthusiasm of enterprises. The policy implication lies in that, in order to improve the efficiency of government subsidies, we should attach importance to the market in regulating resources allocation. “Science and technology is the first productive force,” R&D has promoted scientific and technological progress and knowledge accumulation, and the market has transformed knowledge into productive forces. So the technology and knowledge must be tested by the market to generate benefits in production and operation stages. It is a market behavior to invest resources in R&D, production, and operation stages according to the principle of equal marginal benefits. Excessive R&D inputs and neglect of resource allocation will not effectively promote enterprises innovation.

Based on the classical literatures, this paper constructs two-stage innovation benefit model. But it cannot fully fit the complex reality of innovative process. Moreover, the conclusions drawn from theoretical derivation and numerical simulation need to be further verified by empirical research. These problems will be improved in the follow-up study. This paper emphasizes the balanced allocation of innovative resources in R&D and transformation, and the conclusions are not suitable for basic scientific research, which is theoretical work to obtain the basic principles, not for the purpose of direct market application.

Data Availability

The data supporting the current study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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