

The Symbiotic Effect and Evolutionary Game Analysis of Quantity Procurement System and Innovation Development of Pharmaceutical Enterprises under Government Regulation

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Abstract: The government and pharmaceutical enterprises are the two important subjects in the implementation of the system. On the one hand, the government's implementation of the policy promotes the innovative development of pharmaceutical enterprises, on the other hand, it also realizes the deepening development of the system from the upgrading of drug quality caused by the innovative development of pharmaceutical enterprises, which is conducive to the positive symbiotic effect of the two. Based on the two main bodies of government and pharmaceutical enterprises, this paper reveals the interaction mechanism between the procurement system with quantity and the innovation of pharmaceutical enterprises. Based on the evolutionary game theory, this paper discusses the dynamic selection process between the procurement system with quantity and the innovation and development of pharmaceutical enterprises. Matlab simulation is used to analyze the profit and loss parameter conditions under different stable strategies. The results show that the government should give full play to its macro-control ability in the implementation of the procurement policy with quantity, reasonably control the innovation subsidies to pharmaceutical enterprises so as to maximize the innovation intention of pharmaceutical enterprises and to guide the standardized development of the original drug, generic drug and innovative drug market, accelerate the formation of a reasonable drug price mechanism, and promote the high-quality development of the pharmaceutical industry. Finally, based on the research conclusions, this paper provides reference opinions for the development and improvement of the national drug centralized procurement system, and also provides an important basis for pharmaceutical enterprises to make innovative choices and transformation and upgrading under the background of national centralized procurement.

Keywords: Purchase with quantity, Symbiotic effect, Evolutionary game, Innovative development, Simulation analysis.

1. Introduction

2023 has been the 38th year of China's medical reform. Looking back on the road of China's medical reform, from the initial simplification of administration and decentralization, low-level medical insurance for all, to the property rights reform, the encouragement of market-oriented measures to bring opportunities for restructuring and integration of medical institutions, and to the new transformation of medical and health system reform since the 18th CPC National Congress, the road of the country's medical reform not only shows that the medical reform meets the expectations of the current people, but also shows that China's medical reform still has a long way to go [1]. How to effectively solve the problem of expensive and difficult medical treatment for ordinary people and how to reduce the price of drugs while ensuring the quality of drugs is the key to medical reform. Based on this, in November 2018, at the fifth meeting of the Central Committee for Comprehensive Deepening Reform and Reform, China considered and approved the "Pilot Program for Centralized Drug Procurement under State Organizations". In December of the same year, the "4+7" procurement pilot program was launched by the leading group of medical reform in the State Council, and initial results were achieved. In December 2019, the National Medical Insurance Bureau issued the "Opinions on Doing Well in the Current Drug Price Management Work", which further clarified the deepening reform and development of the volume purchase

system, controlled the trend of rationalization of drug prices, and continued to improve and develop the drug price formation mechanism to truly achieve the goal of benefiting the people. It has become a normal and institutionalized purchase mode to reduce the price of pharmaceutical products through centralized purchase of pharmaceutical products with volume. Pharmaceutical enterprises, as a key part, are facing new challenges. How to grasp the development opportunities, actively carry out innovation and upgrading, break down the development resistance, and efficiently realize the transformation and upgrading of enterprises, while helping to deepen the development of centralized purchase of pharmaceutical products with volume, and more efficiently help to complete the objectives of the new medical reform, are the focus of thinking and attention of pharmaceutical manufacturing enterprises at this stage.

First, the national drug centralized procurement system will further push pharmaceutical enterprises to allocate more innovation costs to the transformation and upgrading of enterprises, so that more capital will flow into the innovation field, thus promoting the innovation development of the entire pharmaceutical industry. Under such a background, innovation plays a decisive role in the development of pharmaceutical enterprises. In order to further highlight and improve the core competitiveness of pharmaceutical enterprises and increase their initiative and bargaining power in the process of centralized purchase of pharmaceutical products, pharmaceutical enterprises should not only assume corporate responsibility to ensure consistency of

pharmaceutical quality, but also continuously increase investment in scientific research and innovation, improve pharmaceutical quality, seek new development momentum and promote high-quality development of pharmaceutical enterprises and pharmaceutical industry.

Secondly, generics still occupy a leading position in the pharmaceutical market in our country, and pharmaceutical enterprises in our country still rely on generics for their development. The more mature generic pharmaceutical companies are the main ones. For these pharmaceutical companies, before the implementation of the volume purchase system, they have a larger profit margin based on lower production costs and "gold sales" and other means, further exacerbating the vicious circle of inflated drug prices. However, with the implementation of the volume purchase system and the generic drug consistency evaluation policy, the disadvantages of the generic drug industry, such as insufficient innovation capability and low market scarcity, are gradually emerging, which not only reduces its profit margin, but also inevitably has a negative impact on its long-term development. Therefore, it is of great significance for pharmaceutical enterprises to enhance their independent research and innovation capabilities.

Third, China's innovative medicine market is still in the primary stage of development, and there is still a big gap compared with developed countries. In 2021, the global sales volume of innovative drugs was approximately US\$ 830 billion, of which the United States accounted for more than half. Among other developed countries, five European countries accounted for 16%, Japan and South Korea accounted for 8%, and China only 3%, far lower than the developed countries' level (Source: EvaluatePharma, BCG, Ping An Securities Institute). On the one hand, this shows that China's pharmaceutical enterprises are still in the stage of insufficient innovation, on the other hand, it also shows the huge potential space for innovation and development. For example, in the 2022 Top25 ranking of global research and development pipeline scale, Jiangsu HengRui ranked 16th (Source: Annual Analysis of Pharmaceutical Research and Development Trends in 2022), and its research and development investment was in the forefront of pharmaceutical companies in China. At the same time, it had a positive role in promoting the output, with significant innovation results. At the same time, research and development innovation has also attracted more attention from pharmaceutical companies. In 2022 alone, the share of China pharmaceutical research and development companies in the global pharmaceutical research and development companies jumped from 9% to 12%, with an increase of 43.3% (Source: Annual Analysis of Pharmaceutical Research and Development Trends in 2022). Innovation-led development has become one of the driving forces for pharmaceutical companies.

In view of this, in order to study the impact of innovation on pharmaceutical companies in the context of volume-based procurement, this paper discusses the innovation incentives of pharmaceutical companies in the context of volume-based procurement from the evolutionary game between government volume-based procurement and pharmaceutical companies' innovation choices, which is of practical significance at a time when volume-based procurement is comprehensively deepening its development. On the one hand, from the perspective of evolutionary game theory, this paper analyzes the evolutionarily stable strategy of volume-based

procurement models and pharmaceutical enterprises' innovative choices and pays attention to the interactive mechanism between pharmaceutical enterprises' innovative development and the deepening development of volume-based procurement systems. On the one hand, through Matlab simulation, the stable conditions of mutual promotion between volume procurement and pharmaceutical enterprise innovation are explained, which provides a reference for the government to guide the development of the market of original research drugs, generic drugs and innovative drugs.

Compared with the existing research, this paper has the following three marginal contributions: With the help of evolutionary game theory and simulation analysis, this paper discusses the innovative development of pharmaceutical enterprises under the background of volume procurement. At the same time, it pays attention to the changing mechanism of innovation benefits, innovation costs and innovation subsidies on pharmaceutical enterprises' innovation choices, and emphasizes the macro-control role of the government.

The content of this paper is arranged as follows: The second part mainly reviews the previous research literature; The third part is mainly from the evolutionary game and the simulation analysis to explain the game subject government and the pharmaceutical enterprise's evolutionary stable strategy choice; The fourth part is the conclusions and policy implications.

2. Review of Relevant Literature

With the continuous expansion of national drug centralized volume procurement in regional scope and drug types, the volume procurement system has had a profound impact on the development of the pharmaceutical industry. As a key link in the pharmaceutical industry, the development of pharmaceutical enterprises under the background of volume procurement has also received more and more research. Based on this, this paper reviews and summarizes the relevant literature from the following three aspects.

2.1. Research on centralized purchase of pharmaceutical products with volume

As an important part of the new medical reform, the purchase of drugs with volume plays a role in controlling the return of drug prices to a reasonable level and guiding the formation of a drug price mechanism, which helps the government achieve the goal of benefiting the people and promote the healthy development of the pharmaceutical market. Li Dongsheng et al. (2019) [20] through the analysis of the "4+7" recruitment model, explained the operation mechanism and feasibility of the "quantity for price" of the purchase with quantity. The purchase with quantity is indeed helpful in solving the problem of high drug prices. Yan Juanjuan, et al.(2023) [21] With the help of the discontinuous time series regression method, by analyzing the sales data of four types of drugs in the market, it shows that Volume purchase is helpful to the decrease drug cost in the short term and the long term, and is helpful to reduce the drug burden of patients. Wang Xiangyin et al. (2022) [22] discussed the impact of the volume procurement model on welfare change from the perspective of drug market economic surplus and explained that volume procurement takes into account both dynamic efficiency and static efficiency, which is beneficial to the improvement of patients' welfare level and social welfare. Yu Qiaoping (2021)[23] takes a specific public

hospital as an example, by constructing an evaluation system of the implementation effect of volume procurement and analyzing the data on the effect of volume procurement, considers that volume procurement has a positive impact on promoting the healthy development of public hospitals and relieving the pressure of medical insurance payment. On the one hand, it will not only increase the cost of enterprises, but also accelerate the elimination of some small and medium-sized enterprises with low degrees of specialization; On the other hand, the expansion of volume procurement may not only reduce the medical cost of public hospitals, but also increase the uncertainty of drug quality and drug types, and may lead to legal risks of pharmacy trusteeship.

2.2. Research on the Impact of Centralized Drug Purchase on Enterprise Innovation

With the normal development of the national drug centralized purchase mode, the innovation development of China's pharmaceutical enterprises has been stimulated, which is beneficial to improving the innovation environment of China's pharmaceutical industry. Zhang Qiuyu et al. (2022) [15] analyzed the changes in the innovation performance of pharmaceutical companies under the background of volume procurement based on the panel data of listed pharmaceutical manufacturing companies in Shanghai and Shenzhen A shares from 2016 to 2020 in our country, and considered that the research and development investment and sales expenses of pharmaceutical companies showed a reverse change relationship, and enhanced the innovation performance of pharmaceutical companies. Luo Zhibo et al. (2022) [14] based on the analysis of the historical evolution, policy motivation and promotion logic of volume-based procurement and its impact on the industrial chain, think that the government is more willing to increase the guidance and support for enterprise innovation while implementing the volume-based procurement system, and gradually separate the innovative pharmaceutical companies and generic pharmaceutical companies to promote the professional development of the pharmaceutical industry. Zhang Qinfang (2022) [15] selected the average value of relevant financial performance indicators before and after the full promotion of the volume procurement policy, explained the reasons for the changes in corporate financial performance from the aspects of resource integration capability and technological innovation capability, and stressed that when an enterprise has sufficient research and development capability, it should comply with the policy guidance in a timely manner and produce innovative drugs, so as to speed up the transformation and upgrading. Yang Xinyue et al. (2019) [27] discussed the influence law of volume procurement on the pharmaceutical market price by using the theory of competitiveness, and found that the volume procurement system not only controls the rational development of pharmaceutical prices, but also promotes the competition in the pharmaceutical market and promotes the innovation and development of pharmaceutical enterprises in our country. In addition, Zhang Xinxin et al. (2017) [2] explained that the innovation incentive of centralized procurement regulation on pharmaceutical enterprises is affected by the platform charging model by means of the multi-stage dynamic game model between the duopoly competition pharmaceutical enterprises and the centralized procurement platform, but the description of volume-based procurement is lacking.

At the same time, based on the application of the

evolutionary game method in pharmaceutical research, such as Song Yan et al. (2016) [28] analyzed the selection of stabilization strategies based on the evolutionary game model of drug safety supervision; Jin Hao et al. (2022) [29] analyzed the impact of factor inputs on the quality of pharmaceutical products based on the evolutionary game model of "pharmaceutical raw and auxiliary materials suppliers—pharmaceutical manufacturers", which provided a theoretical basis for this paper to analyze the long-term complex dynamic development problem between the implementation of the volume procurement system by the government and the innovative choices of pharmaceutical enterprises by using the evolutionary game method.

3. Assumption and Construction of Evolutionary Game Model

3.1. Problem Description

Since the "4+7" pilot project of centralized drug volume procurement was first launched by the National Medical Insurance Bureau in 2018, it has Seven batches of pharmaceutical products were successfully purchased in volume, involving 294 kinds of pharmaceutical products. The centralized purchase mode of pharmaceutical products has become an important way of pharmaceutical products purchase, and tends to be institutionalized and normalized. It is a long and complicated dynamic development process. But at the same time, with the overall development of the centralized purchasing model, more and more pharmaceutical companies are facing the choice of price reduction. On the one hand, this has achieved the goal that the country wants to achieve when the centralized purchasing model starts, and promoted the healthy development of the pharmaceutical industry. On the other hand, this has also brought pressure and opportunities for enterprises to transform and upgrade. More and more pharmaceutical companies are taking innovation and development as the main and long-term task of their development. Therefore, in this part, based on the evolutionary game theory, this paper discusses the game relationship between the government and the pharmaceutical industry, analyzes the strategic choices of both parties in the game with different profit and loss parameters, and through simulation, analyzes and discusses the stable state.

3.2. Basic Assumptions and Model Building

3.2.1. Both sides of the game

The government and pharmaceutical companies play a key role in the centralized drug purchase model. Pharmaceutical companies choose the declared price based on the price cap and the agreed purchase volume stipulated by the government procurement department. Therefore, this paper chooses the government and pharmaceutical companies as both sides of the game, both of which are bounded rational subjects with learning ability, and will adjust their own strategy choices according to each other's strategy changes in the long-term interaction, until the evolution equilibrium is reached.

3.2.2. Set of policies and probability of occurrence

The government and pharmaceutical companies have two strategies to choose from in the game process. The government's strategy set is (volume procurement, centralized procurement), the corresponding probabilities are x ($0 \leq x \leq 1$) and $1-x$ respectively, and the strategy set of pharmaceutical enterprises is (innovation, not innovation), the corresponding probabilities are y ($0 \leq y \leq 1$) and $1-y$

respectively.

3.2.3. Profit and loss parameters and assumptions of both parties in the game

Hypothesis 1: a and b represent the revenue and utility respectively when the government and pharmaceutical companies choose to implement the centralized procurement strategy and have no innovation input; c and d the cost when the government and pharmaceutical companies choose to implement the centralized procurement strategy and have no innovation input respectively.

Hypothesis 2: Δa indicates that when the government and pharmaceutical enterprises choose to simultaneously implement the volume procurement strategy and allocate innovation inputs, the government will improve the medical security system by choosing the volume procurement strategy to motivate pharmaceutical enterprises to carry out technological innovation to improve the quality of drugs, which is conducive to forming a consistent evaluation of the quality of drugs, further solving the problem of "difficulty and high cost of seeing a doctor", highlighting the social functions of the government, and promoting the additional benefits and effects of government performance. At the same time, the government to ensure the smooth implementation of the volume procurement model and the need to consider the introduction of relevant policies, pilot choices and other additional costs to pay for Δc .

Hypothesis 3: Δb indicates that the allocation of innovation inputs by pharmaceutical companies is conducive to accelerating the realization of the additional revenue generated by the transformation and upgrading of their enterprises. At the same time, participating in volume-based procurement can promote the innovative output of pharmaceutical enterprises, with "innovation dividend" (Zhang Jun et al., 2022). Based on the background of volume-based procurement, the sales expenses and marketing promotion costs of pharmaceutical enterprises are reduced to a certain extent, which enables pharmaceutical enterprises to focus more on innovative research and development of pharmaceutical products and quality improvement. Meanwhile, with the development and improvement of the

consistency evaluation system for generic drugs, the relevant policies of volume-based procurement promote the high-quality development of pharmaceutical industry and give pharmaceutical enterprises stronger confidence in innovation. Assuming that the government chooses the volume-based procurement model, the incremental cost paid by pharmaceutical companies for carrying out innovative activities is Δd_1 . If the government chooses the centralized procurement model, the incremental cost paid by pharmaceutical companies for carrying out innovative activities is Δd_2 . Due to the greater demand for innovation of pharmaceutical enterprises under volume procurement, pharmaceutical enterprises have further increased their investment in research and development innovation, but at the same time, they have also obtained more innovation performance and improved their competitiveness, so there are $\Delta d_1 > \Delta d_2$. In addition, the innovative development of pharmaceutical enterprises is conducive to the realization of a virtuous circle of the economy, enhancing social benefits and enhancing consumers' recognition of the government. Therefore, the additional revenue obtained by the government is μ .

Hypothesis 4: β indicates that the government gives subsidies for pharmaceutical innovation and research and development in order to promote the high-quality development of the pharmaceutical industry and accelerate the formation of pharmaceutical industrial clusters. In addition, the government's choice of the volume procurement model is not only conducive to promoting the development of the medical security system, but also conducive to solving the problem of virtual high drug prices and realizing the development of the low-cost and high-quality pharmaceutical value chain. Therefore, the reward obtained by the government for choosing the quantity procurement mode is θ .

Without loss of generality, the above parameters are all greater than zero.

Based on the above profit and loss parameters and assumptions, the game payment matrix between the government and pharmaceutical companies is shown in Table 1.

Table 1. Game payment matrix of government and pharmaceutical enterprises

Both Sides of the Game		Government	
		Purchase with volume	Centralized purchasing
Pharmaceutical enterprise	Innovate	$[b+\Delta b-d-\Delta d_1+\beta, a+\Delta a-c-\Delta c+\mu+\theta-\beta]$	$[b+\Delta b-d-\Delta d_2+\beta, a-c+\mu-\beta]$
	Not innovate	$[b-d, a-c-\Delta c+\theta]$	$[b-d, a-c]$

3.3. Evolutionary Game Analysis between Government and Pharmaceutical Enterprises

3.3.1. Evolutionary Equilibrium Point and Its Stability Analysis

The expected revenue from the implementation of the volume procurement and centralized procurement strategies by the government is (1) and (2) respectively, and the average expected revenue of the government is $\bar{E}(x)$, the corresponding calculated values of the three are as follows:

$$\begin{cases} E(x_1)=y(a+\Delta a-c-\Delta c+\mu+\theta-\beta)+(1-y)(a-c-\Delta c+\theta) \\ E(x_2)=y(a-c+\mu-\beta)+(1-y)(a-c) \\ \bar{E}(x)=x E(x_1)+(1-x)E(x_2) \end{cases} \quad (1)$$

Similarly, the expected earnings of pharmaceutical companies for innovation or not are (1) and (2) respectively, and the average expected earnings of pharmaceutical companies is $\bar{E}(y)$, the corresponding calculated values of the three are as follows:

$$\begin{cases} E(y_1)=x(b+\Delta b-d-\Delta d_1+\beta)+(1-x)(b+\Delta b-d-\Delta d_2+\beta) \\ E(y_2)=x(b-d)+(1-x)(b-d) \\ \bar{E}(y)=y E(y_1)+(1-y)E(y_2) \end{cases} \quad (2)$$

From the expected revenue equations (1) and (2) of the government and the pharmaceutical companies, according to the Malthusian dynamic equation principle, we can get the replication dynamic equations of the government implementing the volume procurement policy and the pharmaceutical companies allocating the innovation input, respectively

$$\begin{cases} F(x) = \frac{dx}{dt} = x(E(x_1) - \bar{E}(x)) = x(1-x)(\theta - \Delta c + y \Delta a) \\ F(y) = \frac{dy}{dt} = y(E(y_1) - \bar{E}(y)) = y(1-y)(x \Delta d_2 - x \Delta d_1 + \Delta b - \Delta d_2 + \beta) \end{cases} \quad (3)$$

According to the replication dynamic equation (3), when $F(x)=0$, $F(y)=0$ we get (0,0), (0,1), (1,0), (1,1), (A,B) are five different equilibrium points of the system, where $A = \frac{\Delta b - \Delta d_2 + \beta}{\Delta d_1 - \Delta d_2}$, $B = \frac{\Delta c - \theta}{\Delta a}$.

Further, the stability of the equilibrium point is analyzed, and the partial derivatives of the replicated dynamic equations of the government and the pharmaceutical enterprises are

obtained with respect to and in turn, and the Jacobian matrix is obtained as follows

$$J = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} = \begin{bmatrix} (1-2x)(\theta - \Delta c + y \Delta a) & x(1-x) \Delta a \\ y(1-y)(\Delta d_2 - \Delta d_1) & (1-2y)(x \Delta d_2 - x \Delta d_1 + \Delta b - \Delta d_2 + \beta) \end{bmatrix} \quad (4)$$

At this time, according to the stability criterion of Jacobian matrix proposed by Friedman, if the equilibrium point of the replicated dynamic equation simultaneously satisfies the following two conditions, the strategy represented by the equilibrium point at this time is evolutionary stability strategy (ESS).

$$\text{tr}(J) = a_{11} + a_{22} < 0;$$

$$\det(J) = \begin{vmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{vmatrix} = a_{11}a_{22} - a_{12}a_{21} > 0.$$

By solving, the values of a_{11} , a_{12} , a_{21} , a_{22} corresponding to the five equilibrium points can be obtained respectively as shown in table 2.

Table 2. Values of a_{11} , a_{12} , a_{21} , a_{22} at equilibrium points

Equalization point	a_{11}	a_{12}	a_{21}	a_{22}
(0,0)	$\theta - \Delta c$	0	0	$\Delta b - \Delta d_2 + \beta$
(0,1)	$\theta - \Delta c + \Delta a$	0	0	$-(\Delta b - \Delta d_2 + \beta)$
(1,0)	$-(\theta - \Delta c)$	0	0	$-\Delta d_1 + \Delta b + \beta$
(1,1)	$-(\theta - \Delta c + \Delta a)$	0	0	$-(\Delta d_1 + \Delta b + \beta)$
(A,B)	0	C	D	0

Where $C = \frac{\Delta b - \Delta d_2 + \beta}{\Delta d_1 - \Delta d_2} (1 - \frac{\Delta b - \Delta d_2 + \beta}{\Delta d_1 - \Delta d_2}) \Delta a$, $D = \frac{\Delta c - \theta}{\Delta a} (1 - \frac{\Delta c - \theta}{\Delta a}) (\Delta d_2 - \Delta d_1)$

As shown in Table 2, there is $a_{11} + a_{22} = 0$ at the point (A,B), and the condition (1) of the stability determination

criterion is not satisfied, so the strategy represented by this point is not an evolutionary stability strategy (ESS). Under the condition that each profit and loss parameter is greater than zero, the stability analysis for the other 4 equilibrium points is shown in Table 3.

Table 3. Stability analysis of equilibrium points

Equalization point	stability	Stable condition
(0,0)	ESS	$\Delta b + \beta < \Delta d_2$ and $\theta < \Delta c$ and $\Delta a > \Delta c - \theta$ or $\Delta b + \beta < \Delta d_2$ and $\theta < \Delta c$ and $\Delta a < \Delta c - \theta$
(0,1)	ESS	$\Delta b + \beta > \Delta d_1$ and $\theta < \Delta c$ and $\Delta a < \Delta c - \theta$ or $\Delta d_2 < \Delta b + \beta < \Delta d_1$ and $\theta < \Delta c$ and $\Delta a < \Delta c - \theta$
(1,0)	ESS	$\Delta b + \beta < \Delta d_2$ and $\theta > \Delta c$ and $\Delta a > \Delta c - \theta$ or $\Delta d_2 < \Delta b + \beta < \Delta d_1$ and $\theta > \Delta c$ and $\Delta a > \Delta c - \theta$
(1,1)	ESS	$\Delta b + \beta > \Delta d_1$ and $\theta < \Delta c$ and $\Delta a > \Delta c - \theta$ or $\Delta b + \beta > \Delta d_1$ and $\theta > \Delta c$ and $\Delta a > \Delta c - \theta$

3.3.2. Result Analysis

Case 1: $\Delta b + \beta < \Delta d_2$, $\theta < \Delta c$. As can be seen from Table 3, at this time (0,0) is ESS, i.e. the sum of the additional revenue obtained from the allocation of innovation input by pharmaceutical enterprises and the innovation subsidy given by the government is less than the incremental cost paid by pharmaceutical enterprises for carrying out innovation activities under the background of volume procurement ($\Delta d_2 < \Delta d_1$), and the incremental revenue obtained from the government's selection of volume procurement mode is less

than the additional cost required for the development and improvement of volume procurement mode. Centralized procurement mode and not carrying out technological innovation have become the preferred strategies of the government and pharmaceutical enterprises. At the same time, in this case, the additional revenue obtained by the government adopting the volume procurement mode is higher or lower than the difference between the additional cost and the incremental revenue. The simulation trend is shown in Fig 1.

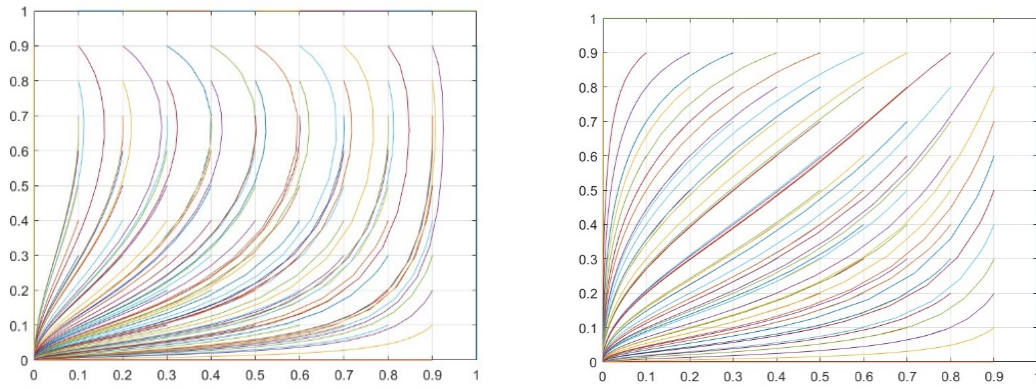


Figure 1. Stability point (0,0) evolution simulation results

As shown in Fig 1, if the proportion of the government implementing the volume procurement gradually decreases, that is, when the volume procurement model is in the initial stage of development, the scope of drugs covered at this time is relatively small, and the consistency evaluation of generic drugs is also in the initial stage of development, the volume procurement model is not attractive enough for some pharmaceutical companies, which results in insufficient attention to the improvement of drug quality and innovation. In the long run, due to the lack of innovation of pharmaceutical companies, It will lead to the low-quality generic drugs entering the medical institutions through "cash sales" to become the norm, and eventually lead to the government's lack of realistic motivation to implement the volume procurement model, and the entire market will inevitably be in a vicious circle of high drug prices. From this, it can be seen that the innovation consciousness of pharmaceutical enterprises is the key to the healthy evolution of the pharmaceutical market and the important driving force for the continuous improvement and development of the

volume-based procurement model.

Case 2: $\Delta b + \beta > \Delta d_1$, $\theta < \Delta c$ and $\Delta a < \Delta c - \theta$. As can be seen from Table 3, at this time (0,1) is ESS, i.e. when the sum of the additional revenue obtained by the pharmaceutical enterprise from allocating the innovation input and the innovation subsidy given by the government is greater than the incremental cost paid by the pharmaceutical enterprise for carrying out the innovation activities under the background of the volume procurement, the incremental revenue obtained by the government in selecting the volume procurement model is less than the additional cost required for developing and perfecting the volume procurement model, and the additional revenue obtained by the government in adopting the volume procurement model is less than the difference between the additional cost and the incremental revenue, the government will select the centralized procurement model and the pharmaceutical enterprise will carry out the technological innovation, the simulation trend of which is shown in Fig 2.

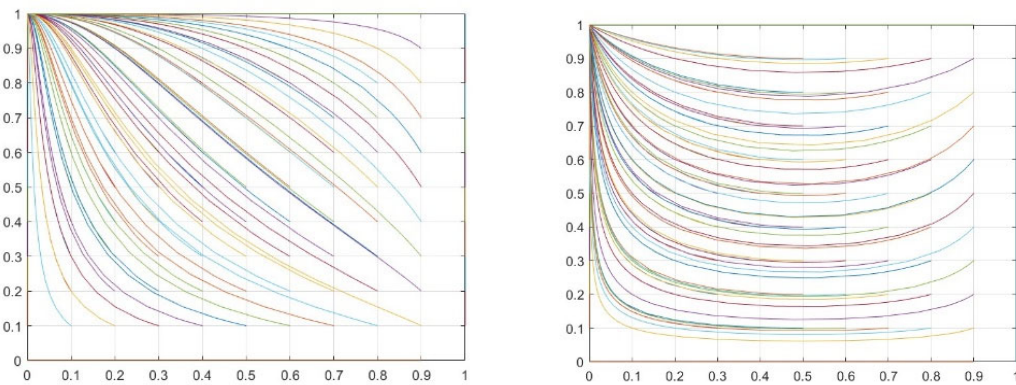


Figure 2. Stability point (0,1) evolution simulation results

Case 3: $\Delta d_2 < \Delta b + \beta < \Delta d_1$ and $\theta < \Delta c$ and $\Delta a < \Delta c - \theta$. As can be seen from Table 3, at this time (0,1) is ESS, i.e. the sum of the additional revenue obtained by pharmaceutical companies from allocating innovation inputs and the innovation subsidies granted by the government is higher than the incremental cost paid by pharmaceutical companies for carrying out innovation activities under the background of centralized procurement but lower than the increase under the background of volume procurement volume cost, when the incremental revenue obtained from the government's selection of volume procurement mode is less than the

additional cost required to develop and perfect the volume procurement mode and the additional revenue obtained from the government's adoption of the volume procurement mode is less than the difference between the additional cost and the incremental revenue, the government will select the centralized procurement mode and the pharmaceutical enterprise will carry out technological innovation, with the simulation trend shown in Fig. 2.

As can be seen from Fig 2, at this time, as the government will pay more attention to the innovation and development of pharmaceutical enterprises and encourage pharmaceutical

enterprises to carry out technological innovation to improve the quality of pharmaceutical products in order to implement the volume procurement model and the implementation of the generic drug consistency evaluation policy, the innovation of pharmaceutical enterprises will be profitable and the pricing power can be preempted at low cost, but at the same time, the implementation cost of the government will be higher, thus plunging into a state of high quality and high price. Although volume procurement has brought about the improvement of the quality of pharmaceutical products, but at the same time with the further virtual high price of pharmaceutical products, the goal of benefiting the people is still not achieved.

Case 4: $\Delta b + \beta < \Delta d_2$ and $\theta > \Delta c$ and $\Delta a > \Delta c - \theta$. As can be seen from Table 3, at this time (1,0) is ESS, i.e. the sum of the additional revenue obtained by pharmaceutical companies from allocating innovation inputs and the innovation subsidies granted by the government is less than the incremental costs paid by pharmaceutical companies for carrying out innovation activities under the background of volume procurement ($\Delta d_2 < \Delta d_1$). When the incremental revenue obtained from the government's selection of the volume-based procurement model is greater than the additional costs it needs to pay to develop and perfect the volume-based procurement model and the additional revenue

obtained from the government's adoption of the volume-based procurement model is higher than the difference between the additional costs and the incremental revenue, the government will select the volume-based procurement model and the pharmaceutical enterprise will not carry out technological innovation. the simulation trend is shown in Fig. 3.

Case 5: $\Delta d_2 < \Delta b + \beta < \Delta d_1$ and $\theta > \Delta c$ and $\Delta a > \Delta c - \theta$. As can be seen from Table 3, at this time (1,0) is ESS, i.e. the sum of the additional revenue obtained by pharmaceutical companies from allocating innovation inputs and the innovation subsidies granted by the government is higher than the incremental costs paid by pharmaceutical companies for carrying out innovation activities in the context of centralized procurement but lower than the incremental costs in the context of volume procurement. When the incremental revenue obtained from the government's selection of the volume-based procurement model is greater than the additional costs it needs to pay to develop and perfect the volume-based procurement model and the additional revenue obtained from the government's adoption of the volume-based procurement model is higher than the difference between the additional costs and the incremental revenue, the government will select the volume-based procurement model and the pharmaceutical enterprise will not carry out technological innovation. the simulation trend is shown in Fig. 3.

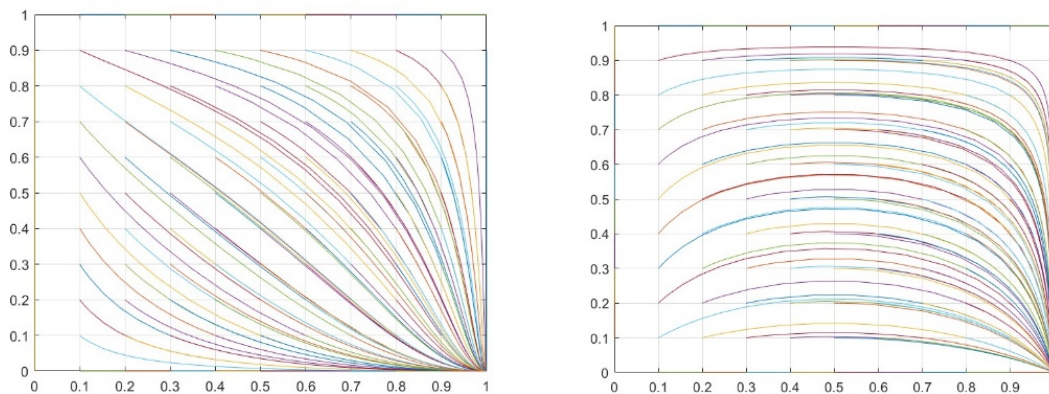


Figure 3. Stability point (1,0) evolution simulation results

As can be seen from Fig. 3, the government has paid enough attention to the volume procurement model, and the pharmaceutical enterprises also have the intention of independent innovation. However, as the innovation incentives given by the government to pharmaceutical companies cannot support them to achieve excess profits, and with volume procurement becoming the mainstream choice, the consistency evaluation of generic drugs will be more comprehensive, the competition among pharmaceutical companies will become more intense, the profit space will be further compressed, and the innovation cost of pharmaceutical companies will be higher. In this case, the competition in the generic drug market will intensify, but it does not promote the innovation and development of pharmaceutical companies, which will eventually lead to the pharmaceutical companies falling into vicious competition and facing the risk of being eliminated by the market. At the same time, the pharmaceutical market will eventually fall into a state of disconnection with high-quality drug demand but without high-quality drug supply.

Case 6: $\Delta b + \beta > \Delta d_1$ and $\Delta a > \Delta c - \theta$. As can be seen from Table 3, at this time (1,1) is ESS, i.e. when the sum of the additional revenue obtained from the allocation of innovation inputs by pharmaceutical enterprises and the innovation subsidy given by the government is greater than the incremental cost paid by pharmaceutical enterprises for carrying out innovation activities under the background of volume procurement, and the additional revenue obtained by the government adopting the volume procurement model is higher than the difference between the additional cost and the incremental revenue, the government will select the volume procurement model, and the pharmaceutical enterprises will carry out technological innovation. At the same time, in this case, the incremental revenue obtained from the government's selection of the volume procurement model is higher or lower than the additional costs it needs to pay to develop and perfect the volume procurement model. The simulation trend is shown in Fig 4.

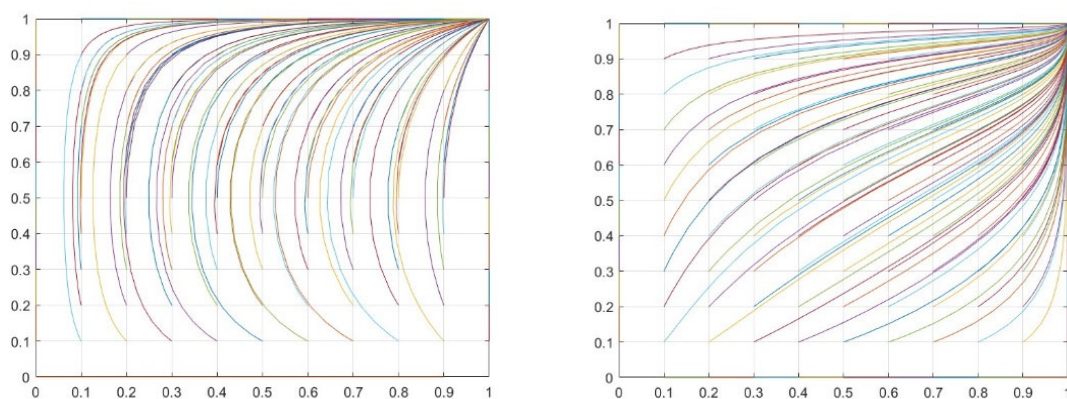


Figure 4. Stability point (1,1) evolution simulation results

As can be seen from Fig 4, the government has a strong determination to implement volume-based procurement in order to benefit the people. While encouraging pharmaceutical enterprises to carry out independent innovation, it is also affected by the innovation and development of pharmaceutical enterprises, which has promoted the deepening development of volume-based procurement model. The strategic choice between the two has produced a positive symbiotic effect, effectively improving government performance to a certain extent, and achieving the government's objectives of rationalizing drug prices and improving the medical security system. At the same time, pharmaceutical companies also attach great importance to the development of innovation and are willing to carry out technological innovation to accelerate their transformation and upgrading. On the one hand, the innovative choice at this time can bring additional benefits and utility to pharmaceutical companies, which enables pharmaceutical companies to further increase their investment in innovation. On the other hand, with the implementation of the normalization of volume procurement, more and more pharmaceutical companies are forced to start innovation and focus more on the innovative pharmaceutical market that can bring higher returns and high-speed growth. At this time, based on the innovation subsidies given by the government and the additional benefits obtained by pharmaceutical enterprises from the innovation development, innovation is a favorable choice for pharmaceutical enterprises, so as to finally realize the ideal state of "high quality and low price" in the pharmaceutical market and positive incentive cycle for the innovative development of pharmaceutical enterprises. It can be seen from this that the key to the evolution of the market to the ideal state is the innovative development of pharmaceutical enterprises and the ability of the government to comprehensively consider the guiding role of the original research medicine, generic medicine and innovative medicine market through the implementation of the volume purchase model, so as to realize the three-win ability of the government, patients and pharmaceutical enterprises to benefit together.

4. Conclusions

With the development of China's centralized drug procurement model and the new demand for "volume-based drug procurement, linking volume with price, and integrating recruitment with purchase", the competition in the drug market has been further intensified. More and more pharmaceutical enterprises have increased their investment in

innovation in order to realize the upgrading and transformation of their enterprises more quickly. While adapting to the new policies, they have grasped the initiative in development. At the same time, the innovative development of pharmaceutical enterprises has also helped to improve the quality of drugs and enrich the innovative drug market, promoted the formation of a consistent drug quality evaluation system, ensured the safety of patients' drugs, and provided a favorable environment for the further development of the volume-based drug procurement system. The positive symbiotic effect between the two is beneficial to the high-quality development of the pharmaceutical market and the improvement of the medical security system. The results of this study show that: pharmaceutical companies allocate innovation investment to research and development will bring cost burden to pharmaceutical companies, making their willingness to innovate is not always significant. But at the same time, based on the realistic background of volume-based procurement, which affects the market competition pattern and intensifies the competition among pharmaceutical enterprises, the government should play a leading role in how to construct and realize an industry system with innovation leading and coordinated development, control the input of pharmaceutical enterprises into innovation cost through a reasonable reward and punishment mechanism and innovation subsidies, and encourage enterprises to innovate and develop in order to realize the coordinated development of enterprise revenue increase and pharmaceutical quality upgrade on the premise of maintaining reasonable market competition, thus providing a solid foundation for the further implementation of volume-based procurement system. At the same time, based on the trade-off process of the interaction between the volume procurement system and innovation, the evolutionary stable strategy is analyzed by establishing the evolutionary game model between the government and the pharmaceutical enterprises and copying the dynamic equation. With the aid of simulation analysis, it is further explained that the government should reasonably guide the market of original research drugs, generic drugs and innovative drugs, control the innovation subsidies for pharmaceutical manufacturing enterprises, continue to deepen the development of the volume procurement system while enhancing the innovation willingness of pharmaceutical enterprises, and finally realize the three-win situation of the government, patients and enterprises.

In the period of continuous improvement and development of the centralized drug purchase model in China, the policy implications of this study include the following three aspects:

1. In order to maintain steady development and mitigate the impact brought by the volume procurement system under the background of volume procurement, pharmaceutical enterprises must adapt to the policy changes in a timely manner and take the initiative to grasp the development opportunities. Based on the actual background of the pharmaceutical industry in China, pharmaceutical enterprises should pay more attention to the importance of innovation-driven development under the background of volume procurement and continuously increase their investment in innovation. On the one hand, they can enhance their core competitiveness and achieve long-term development. On the other hand, based on the normal implementation of volume procurement system, not only the sales expenses of pharmaceutical enterprises are largely avoided, At the same time, the volume-for-price purchase method is also beneficial to pharmaceutical enterprises to form scale effect, thus reducing their unit production cost and providing favorable conditions for enterprises to focus on research and development. Pharmaceutical enterprises should further realize the transformation of pharmaceutical quality through innovation and development, grasp the initiative of innovation, accelerate the transformation and upgrading of themselves, and can send positive signals to the market, attract more financing opportunities and realize their own high-quality development.

2. The deepening development of the volume procurement system cannot be separated from the innovative development of pharmaceutical enterprises. At the same time, the volume procurement system also promotes the independent innovation of pharmaceutical enterprises. When the government subsidizes the innovation of pharmaceutical enterprises, it should strengthen the awareness of the control of government costs. It should not only encourage pharmaceutical enterprises to carry out innovative development to improve the quality of drugs, but also help to form a consistent drug evaluation system to ensure the safety of patients. At the same time, it should also pay attention to the control of innovative investment of pharmaceutical enterprises with innovative advantages, improve the living space of small and medium-sized enterprises, maintain a reasonable market competition, help to control the return of drug prices to a reasonable level, and reduce the drug burden on patients.

3. Innovation investment affects the cost of pharmaceutical enterprises, and thus affects the pricing of pharmaceuticals. As the government's bidding and pricing in the process of volume procurement is based on the general standard pricing of pharmaceuticals, the government procurement department's all-round and multi-angle consideration of pharmaceutical costs is conducive to enhancing the government's bargaining power in the negotiation, reducing the price of pharmaceuticals to a greater extent, controlling the scope of pharmaceutical prices, and promoting the steady development of the pharmaceutical market. At the same time, it also helps the government to build a reasonable reward and punishment mechanism to supervise the pharmaceutical enterprises, reduce the existence of grey space, and promote the high-quality development of the pharmaceutical industry.

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