Analysis and Comparison of China's Biofuel Ethanol Subsidy Modes

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Abstract

Choosing an effective subsidy mode is crucial for promoting the healthy development of the biofuel ethanol industry. After considering the differences in the social welfare effects of different subsidy models, we construct a Stackelberg game model to examine the chain of the fuel ethanol industry consisting of a downstream channel intermediary as the leader and an upstream production enterprise as the follower. We then discuss how the R&D subsidy mode and production subsidy mode affect social welfare, and what kind of subsidy mode should be adopted under different conditions. The study found that different subsidy modes affect corporate profits and consumer surplus by affecting the price and demand of fuel ethanol, which in turn affect the level of social welfare. In addition, the study found that both R&D subsidy mode and production subsidy model are not always efficient. The optimal subsidy mode depends mainly on the R&D difficulty coefficient and the slope of the inverse demand function.

Keywords: fuel ethanol, Stackelberg model, social welfare, subsidy mode.

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1 Introduction

The development of clean, efficient and renewable energy sources to achieve greenhouse gas emission reduction targets, ensure energy supply security, and optimize energy structure has reached a global consensus and has also been an important part of China's energy adjustment strategy. The Chinese government has committed that non-fossil fuel energy source will account for 20% of primary energy consumption by 2030 and strongly supported the development of renewable energy. The 13th Five-Year Plan of China's Energy Development clearly points out that the development of clean, low-carbon energy is the main direction for the adjustment of energy structure, and China insists on the development of non-fossil energy and efficient use of fossil energy.

As an organic component of clean and low-carbon energy, biofuel ethanol plays a key role in replacing fossil energy and reducing atmospheric pollution and carbon emissions. In particular, automobile exhaust emission has become one of the important sources of urban air pollution, as a result of the increasing number of domestic automobiles in China. The Chinese government has established the strategic goal of carbon peak and carbon neutralization. Since biofuel ethanol can significantly reduce greenhouse gas emissions, the development of biofuel ethanol industry has a positive effect on achieving this strategic goal. However, compared to the rapid development of renewable energy industries such as wind power and solar energy, the development of the biofuel ethanol industry has lagged behind. Until now, China's actual annual consumption of biofuel ethanol is only about 3 million tons, which is less than 1% of the nation's refined oil consumption. Compared with the United States, Brazil and other countries, China is still lagging behind (see Figure 1). According to statistics released by Ethanolrfa, the global fuel ethanol production in 2020 was 26,059 million gallons, of which the USA and Brazilian production were 13,926 million gallons and 7,930 million gallons, respectively, accounting for 53.4% and 30.4% of global fuel ethanol production. China's output is 880 million gallons, which was only 3.4% of global biofuel ethanol production.

As a strategic emerging industry, the scale and rate of development of the biofuel ethanol industry is closely related to policy support. In the initial stage of industrial development, the willingness of enterprises to actively invest is weak due to the uncertainties in technology, market demand and so on. In addition, the existence of externality problems also makes it impossible for the equilibrium price to accurately reflect the social costs and benefits

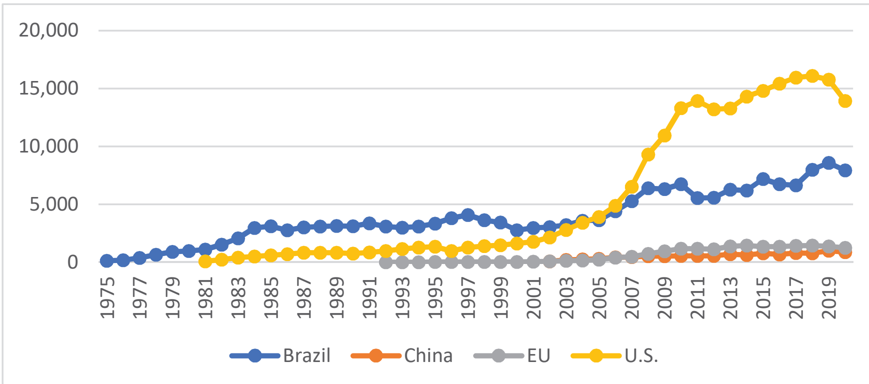

Figure 1 Comparison of fuel ethanol production in various countries (Unit: Million Gallons).
Source: http://www.ethanolrfa.org/resources/industry/statistics/; http://www.earth-policy.org/data_center/C23.

of biofuel ethanol production enterprises, thus resulting in "market failures." Therefore, in order to make up for the lack of market forces and correct the negative externalities of traditional oil enterprises and positive externalities of biofuel ethanol enterprises, it is necessary for the government to provide appropriate market intervention through policy support [1–3]. In practice, countries all over the world have introduced series of incentive policies to promote the development of biofuel ethanol industry. For example, the U.S. government has formulated and successively promulgated the Energy Tax Act, the Alternative Motor Fuels Act, the Energy Policy Act, the Agricultural Act, etc., which provide multidimensional subsidies for production, R&D, consumption and so on, and have greatly increased the enthusiasm of corporate investment.

China also began to propose a strategy for developing biofuel ethanol from the end of the last century. Since 2002, the Chinese government has formulated a number of preferential policies such as taxation and financial subsidies to appointed biofuel ethanol production enterprises with a "cost plus profit" subsidy model in order to solve the problem of "aged grain" (refers to food that has been out of standard for long-term (more than 3 years) storage and whose Aspergillus flavus has exceeded the standard and can no longer be used directly as a ration). This has greatly stimulated the development of the industry (see Figure 2). However, this also brings a series of problems such as inefficient investment, high production costs,

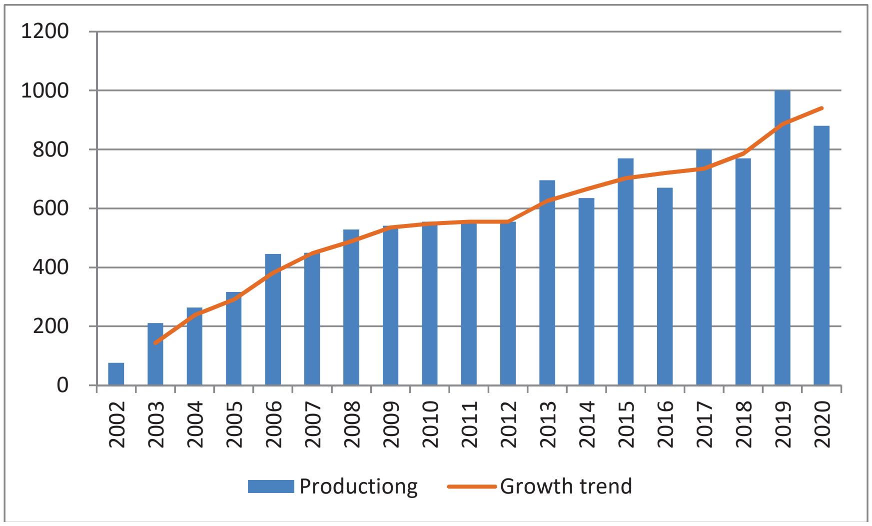

Figure 2 Trend of fuel ethanol production growth in China.
Source: http://www.ethanolrfa.org/resources/industry/statistics/; http://www.earth-policy.org/data_center/C23.

increase in financial burden, and food insecurity. With the realization of the destocking target of aging grain in 2005, the Chinese government gradually reduced subsidies for biofuel ethanol, and changed the subsidy model to fixed subsidies in order to stimulate enterprises to improve technology and reduce production costs. After 2006, the government further adjusted its subsidy model to an elastic subsidy mechanism linked to oil prices, reflecting the country's development intention to gradually liberalize the market and achieve full marketization of biofuel ethanol. In 2017, fifteen departments such as the National Development and Reform Commission and the National Energy Administration jointly issued the "Implementation Plan for Expanding Biofuel Ethanol Production and Promoting the Use of Vehicle Gasoline" (hereinafter referred to as the Implementation Plan), which requires all relevant units to vigorously develop cellulose, biofuel ethanol and other advanced biological liquid fuels. According to the Implementation Plan, the full coverage of vehicle ethanol gasoline will basically be achieved nationwide by 2020. According to the calculation of 10% of the total vehicle gasoline consumption, by 2020, China will need more than 10 million tons of biofuel ethanol by 2020. However, the current capacity under construction and planning is less than 5 million tons per year (the capacity of some non-approved projects cannot be counted), and there is still a large gap between the policy goals. Affected by the epidemic and food security issues, the plan had not been effectively implemented. However, it is foreseeable that the future market space for biofuel ethanol is still huge. From an economic point of view, food and cassava ethanol can only be profitable when Brent's oil price is above US$60 per barrel, but cellulosic ethanol, which is the key development in the future, cannot operate normally without high government subsidies. So it needs the key support of the policy.

Judging from the policy practice of various countries in the world, and due to financial pressure, the subsidy method and intensity are constantly adjusted according to the development status of the biofuel ethanol industry. The adjustment of subsidy policies will affect the welfare of producers and consumers, and thus influence the final policy effect. Under normal circumstances, market intervention will cause unnecessary loss of social welfare. However, strategic emerging industries need appropriate policy incentives to promote their continuous development. Therefore, it is necessary to explore the impact of different subsidy policy modes on stakeholders from the perspective of social welfare, in order to determine the optimal subsidy policy model and provide policy makers with scientific-oriented policy recommendations. This is crucial for the healthy development of the biofuel ethanol industry.

2 Literature Review

The biofuel ethanol industry has great potential for development. All countries adopt different degrees of subsidies and subsidy mode to promote the development of the biofuel ethanol industry in specific policy practices. However, there is still some debates in the academic community regarding the legitimacy and effectiveness of government subsidies. Xu Jiayun et al. [4] used propensity score matching and survival analysis methods to examine the micro effects of government subsidies on business survival, and found that moderate government subsidies can significantly prolong business continuity. Peters et al. [5] believed that at a specific stage of industrial development, reasonable industrial support could make up for the inadequacies of market resource allocation and improve the efficiency of resource allocation. However, industrial support policies are not always effective. Robinson et al. [6] believed that excessive market intervention would weaken the competitiveness that would benefit consumers and politicize the energy market. As a result, society would pay a high price to achieve environmental goals and ensure energy supply security.

Existing research in China mainly focused on the impact of China's biofuel ethanol industry development on agricultural product prices, food security, etc. [7, 8]. Research on policy support focused on policy reviews, comparison of domestic and foreign policies [9, 10]. From the perspective of social welfare, foreign scholars had conducted useful explorations of the research on biofuel ethanol support policies. Gorter et al. [11] used economic cost-benefit analysis methods to evaluate the effectiveness of biofuel ethanol policy in achieving energy, environment, and agricultural policy objectives. It concluded that the subsidy policy would create undesirable interactive effects and lead to the loss of social welfare. They also further analyzed the impact of biofuel ethanol on the welfare of both tax incentives and mandatory share, and believe that when the two coexist, the beneficiaries of the subsidy policy are fossil fuel consumers rather than biofuel consumers [12]. Some scholars analyze from the angle of uncertainty, and conclude that uncertainty factors have an impact on the efficiency of subsidies. Some even conclude that under uncertainty, the reduction of consumption tax on fuel ethanol is redundant [13]. Cotti et al. [14] used a fixed-effect panel model to quantitatively measure and analyze the impact of government subsidies and tax deductions on the US ethanol industry based on data from US states from 1980 to 2007. The study showed that state government subsidies affected the location of ethanol companies. In states where there is a large potential for corn production, the incentive effect of the subsidy policy is significant. Lapan et al. [15] assessed biofuel support policy by constructing an overall equilibrium and open economic model. The results of the study showed that the combination of biofuel subsidies and fuel tax can improve the level of social welfare.

Through the review of the existing literature, it can be found that domestic scholars do not pay enough attention to the social welfare effects of biofuel ethanol subsidy policy. Although foreign scholars have conducted some beneficial exploration and research on this aspect, the research findings are not consistent. In addition, China energy systems, policies and regulations, market maturity, etc are different from those of other countries. The results of these countries have limited reference for the development of China's biofuel ethanol policy formulation. Therefore, it is necessary to conduct in-depth research on China's biofuel development support policy from the perspective of social welfare and in light of the actual situation in China. In decision-making actions, there is a clear master-slave relationship between participants in fuel ethanol production and sales, in view of this, this paper adopts the Stackelberg game model of upstream and downstream enterprises, among which the main party is an oil enterprise, and the second party is an ethanol producer, to study the impact of different subsidy policy of biofuel ethanol production and sales on social welfare. The impact is expected to provide a reference for the Chinese government to improve its subsidy policy and promote the healthy development of the biofuel ethanol industry.

3 Research Hypothesis and Model Description

The production of biofuel ethanol in China has obvious characteristics of government support, including appointed production, orientation sales, government pricing, and government fixed subsidies. At present, obtaining government approval and subsidies are necessary prerequisites for the start-up of biofuel ethanol production enterprises. Changes in government policies are crucial to the volatility of biofuel ethanol production. The pilot district governments have issued market closure regulations in the form of government orders. All gas stations in the same region uniformly sell ethanol gasoline, ensuring the promotion of biofuel ethanol. Biofuel ethanol production enterprises can only sell biofuel ethanol to Sinopec and China National Petroleum (CNPC), who then mix and match the biofuel ethanol into vehicle ethanol gas to sell to auto users. Sinopec and CNPC are called the channel intermediary. Therefore, in the production and sale of biofuel ethanol, the channel intermediary is in a dominant position, and the purchase price influences the operational decision of the biofuel ethanol production enterprise, which is in a subordinate position. According to the reality of China's biofuel ethanol market and the needs of model analysis, the following hypotheses are proposed:

(1) The original production cost of the unit product of the biofuel ethanol production enterprise is s, which can reduce production costs through R&D or the development of new products.
(2) The channel intermediary purchases biofuel ethanol from biofuel ethanol production enterprises and add it to refined oil products. Assuming no reprocessing costs occur in this process, we only consider the cost of sales and the unit cost of sales is c.
(3) The inverse demand function of the channel intermediary's final product in the market is $p = a - bq$, p and q are the price and demand of biofuel ethanol respectively in the end market; the gap between the final sales price of biofuel ethanol and the purchase price is t.
(4) R&D investment by biofuel ethanol producers can only bring about a reduction in production costs without changing the nature of the final

product. Based on the assumption of the A-J model, it can be assumed that the R&D cost to be invested is $rx^2/2$ for each unit of production cost reduction x, in which r is the degree of difficulty of R&D. The larger the value, the greater the R&D difficulty. Therefore, the production cost function of a biofuel ethanol production enterprise can be expressed as $c(q, x) = (s - x)q, x$ is the unit product cost that the biofuel ethanol production enterprise can reduce after investing in R&D costs.

(5) The channel intermediary is the forerunner of the Stackelberg game. First, the purchase price of biofuel ethanol is determined by the channel intermediary, and the biofuel ethanol production enterprise as the latter party determines its output and R&D investment level based on the purchase price. All participants aim at maximizing profits. The upstream enterprise's production capacity can meet the needs of the downstream enterprises, and the supply capacity of the downstream enterprises can meet market demand.

(6) The government starts from the overall situation and subsidizes the participants with the goal of maximizing social welfare. The government can choose one of two subsidy modes: the R&D subsidy mode and the production subsidy mode. e and f represent the government's subsidy for the unit production of the producer and the R&D investment subsidy rate respectively. $e, f \geq 0$, when the value is zero, the government does not provide subsidies.

Based on the above assumptions, the profit function of a biofuel ethanol production enterprise can be expressed as:

$$\pi_1 = (p - t - s + x + e)q - \frac{(1 - f)rx^2}{2} \tag{1}$$

The profit function of the channel intermediary can be expressed as:

$$\pi_2 = (t - c)q \tag{2}$$

According to the literature [16], consumer surplus in the terminal market can be expressed as:

$$\text{CS} = \frac{1}{2}bq^2 \tag{3}$$

The level of social welfare is the sum of producer surplus, consumer surplus and the surplus of environmental benefits brought by biofuel ethanol instead of fossil fuel energy minus government subsidies, while producer surplus can be expressed by the producer's profit. h indicates the incremental environmental benefits of replacing fossil fuel energy with unit biofuel ethanol. Then, the level of social welfare can be expressed as:

$$\mathrm{SW} = \pi_1 + \pi_2 + CS + hq - eq - \frac{frx^2}{2} \tag{4}$$

From the perspective of the entire game process, the channel intermediary first determines the optimal fuel ethanol product purchase volume based on the purchase price, and the biofuel ethanol production enterprise determines its optimal strategy according to the choice of t of the channel intermediary. To use the inverse induction method, the first derivative of q, and x for the profit function π_1 of the biofuel ethanol production enterprise is first calculated, and order $\partial\pi_1/\partial q = 0$, $\partial\pi_1/\partial x = 0$, that is:

$$\begin{aligned} \partial\pi_1/\partial q &= a + e - s - t + x - 2bq \\ \partial\pi_1/\partial x &= q - (1-f)rx \end{aligned} \tag{5}$$

q and x are obtained by the optimal response expression for t:

$$\mathrm{q} = \frac{(1-f)(a+e-s-t)r}{2(1-f)br - 1} \tag{6}$$

$$x = \frac{a+e-s-t}{2(1-f)br - 1} \tag{7}$$

Substituting Equations (6) and (7) into Equation (2) and making $\partial\pi_2/\partial t = 0$, the optimal price gap between the final sales price of biofuel ethanol and the purchase price is obtained:

$$t^* = \frac{a+c+e-s}{2} \tag{8}$$

Substituting Equation (8) into Equations (6) and (7), respectively, the optimal production and optimal research and development investment for biofuel ethanol production company are obtained:

$$q^* = \frac{(1-f)(a+e-c-s)r}{2[2(1-f)br - 1]} \tag{9}$$

$$x^* = \frac{a+e-c-s}{2[2(1-f)br - 1]} \tag{10}$$

From Equations (8) to (10), the following equations can be further obtained:

$$\pi_1^* = \frac{(1-f)(a+e-c-s)^2 r}{8[2(1-f)br-1]} \tag{11}$$

$$\pi_2^* = \frac{(1-f)(a+e-c-s)^2 r}{4[2(1-f)br-1]} \tag{12}$$

$$CS^* = \frac{(1-f)^2 br^2 (a+e-c-s)^2}{8[2(1-f)br-1]^2} \tag{13}$$

$$SW^* = \frac{[7b(1-f)^2+2f-3](a+e-c-s)^2 r}{8[2(1-f)br-1]^2} + \frac{(1-f)(h-e)(a+e-c-s)r}{2[2(1-f)br-1]} \tag{14}$$

4 Social Welfare Effects of Different Subsidy Modes

4.1 The Government's Single Subsidy Mode for R&D Investment in the Biofuel Ethanol Production Enterprise

Technological innovation is a central link in cultivating and developing strategic emerging industries. The foundation and support for the development of strategic emerging industries is the development and application of new technologies. Without strong technical support, there will be no healthy and rapid development of emerging industries. However, technological innovation has a spillover effect, so that innovative enterprises cannot get all the benefits of innovation. This results in the lack of corporate investment in R&D, so the government should give a certain R&D subsidy to innovative companies to increase their innovation initiative. In addition, problems such as learning failures, cognitive barriers, and lock-in, etc., are also important causes of innovation in emerging industries at the initial stage of industrial development, and require the active guidance of the government. Therefore, R&D subsidies are commonly used by Chinese governments at all levels to promote strategic emerging industries. Governments at all levels try to provide direct subsidies for R&D activities of strategic emerging industries, thereby reducing their R&D costs and stimulating technological innovation. In order to increase the R&D investment of biofuel ethanol production enterprises, it is assumed that the government adopts a R&D investment subsidy mode with a subsidy rate of f, $0 < f < 1$. If the government adopts a single subsidy mode, $e = 0$. According to Equations (9)–(10), the optimal production and optimal R&D investment for the biofuel ethanol production enterprise can be modified to:

$$q^{**} = \frac{(1-f)(a-c-s)r}{4(1-f)br-2} \tag{15}$$

$$x^{**} = \frac{a-c-s}{4(1-f)br-2} \tag{16}$$

Similarly, according to Equations (11) to (14), the equilibrium profits of the biofuel ethanol production enterprise and the channel intermediary, the consumer surplus, and the social welfare level can be modified to:

$$\pi_1^{**} = \frac{(1-f)(a-c-s)^2 r}{8[2(1-f)br-1]} \tag{17}$$

$$\pi_2^{**} = \frac{(1-f)(a-c-s)^2 r}{4[2(1-f)br-1]} \tag{18}$$

$$CS^{**} = \frac{(1-f)^2 br^2 (a-c-s)^2}{8[2(1-f)br-1]^2} \tag{19}$$

$$SW^{**} = \frac{[7b(1-f)^2+2f-3](a-c-s)^2 r}{8[2(1-f)br-1]^2} + \frac{(1-f)(a-c-s)hr}{2[2(1-f)br-1]} \tag{20}$$

The government is pursuing the maximization of social welfare. For Equation (20), from the first-order condition $\partial SW^{**}/\partial f = 0$, the government's optimal R&D investment subsidy rate for biofuel ethanol production enterprise is obtained:

$$f^{*} = \frac{(3a+4h-3c-3s)br-(a+2h-c-s)}{(5a+4h-5c-5s)br} \tag{21}$$

Substituting the above equation into Equations (17) to (20), respectively, we can obtain:

$$\pi_1^{**} = \frac{(2br+1)(a-c-s)^2 + 2h(a-c-s)}{8b(4br-3)} \tag{22}$$

$$\pi_2^{**} = \frac{(2br+1)(a-c-s)^2 + 2h(a-c-s)}{4b(4br-3)} \tag{23}$$

$$\mathrm{CS}^{**} = \frac{[(2br+1)(a-c-s)+2h]^2}{8b(4br-3)^2} \tag{24}$$

$$SW^{**} = \frac{(a-c-s+2h)^2 + br(a-c-s)[7(a-c-s)+8h]}{8b(4br-3)^2} \tag{25}$$

Assuming that the equilibrium profit of the biofuel ethanol production enterprise without R&D investment is π_1^0, the necessary condition for the enterprise to invest in R&D is to obtain greater profits through R&D investment, that is, there must be $\pi_1^* > \pi_1^0$. Following the above-mentioned solution idea, we find that the profit of the biofuel ethanol production enterprise without R&D investment is $\pi_1^0 = (c+s-a)^2/(16b)$. If there is a R&D investment subsidy, the necessary condition for the enterprise to conduct R&D is:

$$\begin{aligned}\pi_1^{**} - \pi_1^0 &= \frac{(2br+1)(a-c-s)^2 + 2h(a-c-s)}{8b(4br-3)} - \frac{(a-c-s)^2}{16b} \\ &= \frac{5(a-c-s)^2 + 4h(a-c-s)}{16b(4br-3)} > 0 \end{aligned} \tag{26}$$

According to the inverse demand function $p = a - bq$, the maximum market price of the biofuel ethanol is a, and it must be $a > c + s$. Since the parameters set in the model are all positive, in order to make inequality (16) true, there must be:

$$16b(4br-3) > 0 \tag{27}$$

that is

$$r > \frac{3}{4b} \tag{28}$$

When there is no subsidy for R&D investment, the necessary condition for the enterprise to carry out R&D is:

$$\pi_1^* - \pi_1^0 = \pi_1^* = \frac{(a-c-s)^2 r}{8(2br-1)} - \frac{(a-c-s)^2}{16b} = \frac{(a-c-s)^2}{16b(2br-1)} > 0 \tag{29}$$

that is

$$r > \frac{1}{2b} \tag{30}$$

Obviously, $\frac{3}{4b} > \frac{1}{2b}$. Therefore, the existence of R&D investment subsidy will enable the enterprise to drive more difficult R&D activities.

4.2 The Government's Single Subsidy Mode for Production of the Biofuel Ethanol Production Enterprise

Compared with traditional fossil fuels, the production cost of biofuel ethanol is relatively high. The existing production scale and technical level lead to a lack of market competitiveness for biofuel ethanol, especially in the context of relatively low international oil prices. If there is no national subsidies, biofuel ethanol enterprises will face losses. In order to improve the market-oriented competitiveness of biofuel ethanol enterprises, realize the development of biofuel ethanol energy substitution, protect the environment and increase employment, a wide range of financial and tax subsidies have been carried out in both developed and underdeveloped market economies. From 2002, the Chinese government has adopted some subsidy models, such as actual subsidy for "cost plus profit", fixed subsidy for unified subsidy standards, and flexible subsidy linked to oil prices, for biofuel ethanol enterprises. How much subsidy the biofuel ethanol production enterprise can obtain is closely related to the output. That is, government subsidies are based on the output of the enterprise. We can classify these subsidies as the production subsidy model. In order to promote the production of the biofuel ethanol enterprise, it is assumed that the government grants the enterprise unit product subsidy e. Consistent with the above-mentioned solution idea, assuming $f = 0$, we can obtain the government's optimal unit product subsidy for the fuel ethanol production enterprise:

$$e^* = \frac{(3br-1)(a-c-s) + 2h(2br-1)}{br-1} \tag{31}$$

The optimal production and optimal R&D investment for the biofuel ethanol enterprise is:

$$q^{***} = \frac{(a-c-s+h)r}{br-1} \tag{32}$$

$$x^{**} = \frac{a-c-s+h}{br-1} \tag{33}$$

Combining Equations (32) and (9), we get

$$q^{***} - q^* = \frac{(2br-1)(3br-1)(a-c-s) + 8hbr(br-1) + 2h}{2b(br-1)(4br-3)},$$

that is, the production subsidy is given to the biofuel ethanol production enterprise to increase the volume of production.

The equilibrium profits of the biofuel ethanol production enterprise and the channel intermediary, the consumer surplus, and the total social welfare are:

$$\pi_1^{***} = \frac{(2br-1)(a-c-s+h)^2 r}{2(br-1)^2} \quad (34)$$

$$\pi_2^{***} = \frac{(2br-1)(a-c-s+h)^2 r}{(br-1)^2} \quad (35)$$

$$CS^{***} = \frac{b(a-c-s+h)^2 r^2}{2(br-1)^2} \quad (36)$$

$$SW^{***} = \frac{(a-c-s+h)^2 r}{2(br-1)} \quad (37)$$

When $r > \frac{1}{2b}$, it can be seen that $q^{***} - q^* > 0$, indicating that when the government gives production subsidies to the biofuel ethanol production enterprise, it can increase its production. At this time, the equilibrium profits of the biofuel ethanol production enterprise and the channel intermediary, the consumer surplus, and the total social welfare are positive, indicating that the output of the biofuel ethanol production enterprise can benefit all parties.

5 Analysis and Discussion of Results

Regardless of the type of subsidy mode adopted by the government, the ultimate goal is to increase the level of social welfare. Under this government goal, the above two subsidy models can be compared and analyzed.

According to formula (14), the total social welfare level can be calculated in the absence of any subsidies.

$$SW_0^* = \frac{[(7br-3)(a-c-s)^2 - 4h(2br-1)]r}{8(2br-1)^2} \quad (38)$$

Using Equations (25) and (38), we can calculate that the increase in social welfare caused by R&D subsidies is

$$\Delta_f = SW^{**} - SW_0^* = \frac{[(3br-1)(a-c-s) + 2h(2br-1)]^2}{8b(4br-3)(2br-1)^2} \quad (39)$$

Combining Equations (37) and (38), we can calculate that the increase in social welfare caused by production subsidies is

$$\Delta_e = SW^{***} - SW_0^* = \frac{r[(3br-1)(a-c-s)+2h(2br-1)]^2}{8(br-1)(2br-1)^2} \quad (40)$$

From Equation (28), we can see that in the R&D subsidy mode, $r > 3/4b$, then $4br - 3 > 0$, so $\Delta_f > 0$, which means that the government R&D subsidies to the biofuel ethanol enterprise can improve the level of social welfare. Similarly, when $r > 1/b$, $\Delta_e = SW^{***} - SW_0^* > 0$, the government's production subsidies for the biofuel ethanol enterprise can increase the social welfare level. Since there is $r > 1/2b$ in the absence of subsidies, we can see from the above analysis that when $1/2b < r < 3/4b$, the government adopts the R&D subsidy mode and does not increase the level of social welfare. When $1/2b < r < 1/b$, the government adopts the production subsidy model that is also not conducive to increasing the level of social welfare. When $3/4b < r < 1/b$, the production subsidy mode is inefficient, while the R&D subsidy mode can increase the social welfare level. Obviously, the R&D subsidy mode is better than the production subsidy mode.

$$SW^{**} - SW^{***} = \frac{[(3br-1)(a-c-s)+2h(2br-1)]^2}{8b(br-1)(4br-3)} \quad (41)$$

When $3/4b < r < 1/b$, the social welfare effect of the R&D subsidy mode is better than the production subsidy mode. Therefore, we only discuss the situation in $r > 1/b$. For Equation (47), whether $SW^{**} - SW^{***}$ is greater than zero or not depends on the value of $(br-1)(4br-3)$. When $r > 1/b$, $(br-1)(4br-3) > 0$, $SW^{**} - SW^{***} < 0$. That is, although the production subsidy and R&D subsidy models can increase the social welfare level, the production subsidy model is better than the R&D subsidy mode. In addition, through further calculations, it can be seen that under the effective subsidy mode, both the R&D subsidy mode and the production subsidy mode not only increased the level of social welfare, but also increased corporate profits and consumer surplus. The incremental value of environmental benefits brought by the use of unit biofuel ethanol as a substitute for fossil energy only affects the size of the enterprise's equilibrium profits and the level of social welfare. The greater the value of h, the greater the equilibrium profits of the enterprise and the level of social welfare. The optimal subsidy mode is independent of the value of h, that is, it will not affect the government's decision on the choice of subsidy mode. The above analysis and comparison can be summarized in Table 1.

Table 1 Results of comparative analysis of social welfare effects of different subsidy modes

r	Social Welfare Effect		Mode Selection
	R&D Subsidy	Production Subsidy	
$1/2b < r < 3/4b$	Invalid	Invalid	No
$3/4b < r < 1/b$	Valid	Invalid	R&D subsidy
$r > 1/b$	Valid	Valid	Production subsidy

The results of the above analysis are basically consistent with the policy practices of the world's major biofuel ethanol producing countries. For example, in the early stage of the development of the biofuel ethanol industry, the United States focused on subsidies for corporate R&D investment. The federal government spent about 15 million dollars on R&D of biofuel ethanol annual around 1980. These expenditures increased in the 1990s. In fact, in the United States, research and application of biofuel ethanol technology began in the 1930s. Therefore, in the early 1980s, the difficulty in research and development of biofuel ethanol with corn as the main raw material was basically at the medium level, and the R&D subsidy model was relatively more effective. However, China began to vigorously develop biofuel ethanol in the early 21st century. At this time, the biofuel ethanol technology using corn and other grains as the main raw material had become mature, and the difficulty of further research and development was relatively low. Therefore, the efficiency of R&D subsidies is relatively low. China also did not adopt the R&D subsidy mode at this stage. However, in order to digest "aged grain" and stimulate the rapid development of the biofuel ethanol industry, China mainly adopted the production subsidy mode. It had been proven that the production subsidy mode also brought many challenges such as a heavy financial burden and inefficient production and operation of enterprises, even though it greatly promoted the rapid development of the biofuel ethanol industry. Therefore, starting in 2012, the Ministry of Finance of China issued a notice requesting the reduction of financial subsidies for biofuel ethanol production enterprises. The subsidy for biofuel ethanol for G1, G1.5, and G2 generation was reduced. The subsidies for grain biofuel ethanol decreased from 1,883 yuan/ton in 2005 to zero in 2016, while subsidies for non-grain biofuel ethanol, with cassava as raw material, was also cancelled in 2017.

6 Numerical Simulation

Assigning parameters to the model, we can more intuitively analyze the impact of parameter changes on the results of the model through numerical simulation. To simplify the analysis, assuming $b = 1$, according to the inverse demand function $p = a - bq$, parameter a can be understood as the biofuel ethanol market demand potential. Given the parameter $s = 10$ and $c = 0.1$, we focus on analysing how the biofuel ethanol market demand potential a, the R&D difficulty index r and the environmental benefit factor h affect the optimal R&D subsidy rate, the optimal unit product subsidy, and the social welfare level. We divide R&D difficulties and environmental benefits into four categories: [high R&D difficulties, high environmental benefits], [high R&D difficulties, low environmental benefits], [low R&D difficulties, high environmental benefits], [low R&D difficulties, low environmental benefits]. Based on the results of the above analysis, when $r < 3/4b$, the two subsidy modes are inefficient. When $3/4b < r < 1/b$, only the R&D subsidy mode is efficient. When $r < 1/b$, both subsidy modes are efficient. Therefore, to compare the social welfare effects of different subsidy modes, it is only meaningful to make a comparison in the case of $r > 3/4b$. Let r be 0.8 and 1.5, and h equal to 0.2 and 1.

From Figure 3, we find that when the environmental benefits of biofuel ethanol are large, regardless of the level of difficulty in research and development, the optimal R&D subsidy rate will increase with the growth of market demand potential. When the environmental benefits of fuel ethanol are small, the optimal R&D subsidy rate decreases as the market demand potential grows. According to Figure 4, the optimal production subsidy increases as the market demand potential grows in the four cases. It can be further seen that when the R&D difficulty is high, the rate of increase of the optimal production subsidy is faster than that of lower environmental benefits, regardless of environmental benefits.

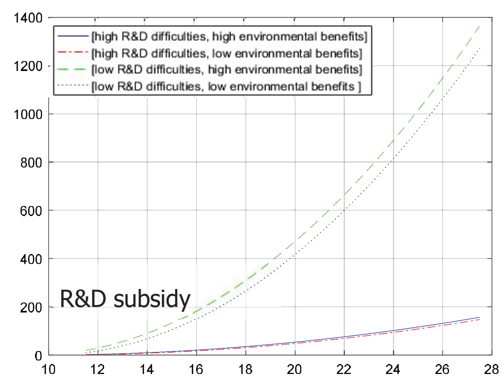

Figure 3 Effect of parameter change on the optimal R&D subsidy rate.

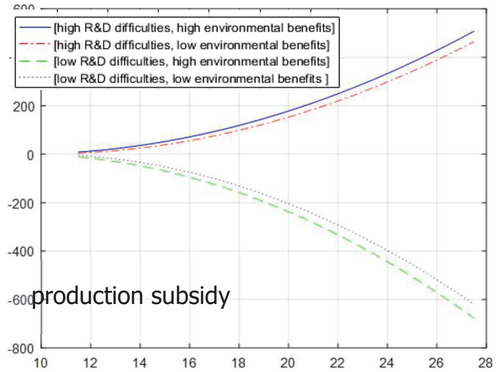

Figure 4 Effect of parameter change on the optimal production subsidy.

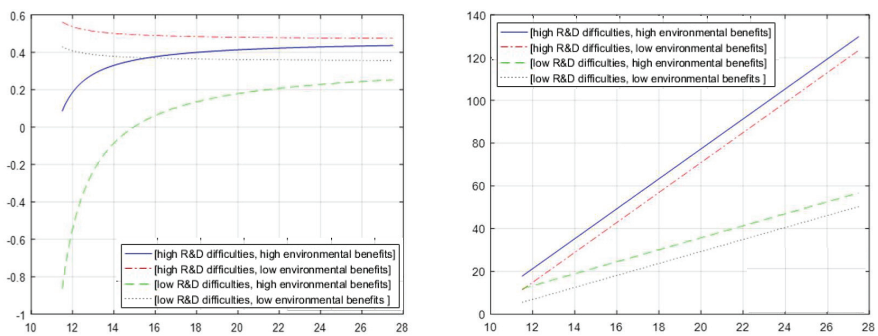

Figure 5 Effect of parameter change on the social welfare level under the different subsidy modes.

As shown in Figure 5, the level of social welfare is increasing in all the four situations under the R&D subsidy model, indicating that the greater the demand potential of the market, the greater the intensity of R&D subsidies affecting the level of social welfare, and the greater the environmental benefits under the same conditions. When the environmental benefits are fixed, the smaller the difficulty of research and development, the greater the impact of R&D subsidies on the level of social welfare.

Under the production subsidy mode, the level of social welfare is negative and declining when the R&D difficulty is small, indicating that the production subsidy mode in this case is inefficient. In other words, it is only in the case of high R&D difficulties that the impact of the production subsidy mode on social welfare level is positive, and the social welfare level is positive. In the case of high R&D difficulties, the level of social welfare is increasing with the increase in market demand potential. Under the same conditions, the greater the environmental benefits, the more obvious the impact of the production subsidy mode on the level of social welfare. From a horizontal comparison perspective, under the conditions of high R&D difficulty, the social welfare effect of the production subsidy mode when other conditions are certain is greater than the social welfare effect of the R&D subsidy mode.

7 Conclusions

The energy and environment issues facing China's economic and social sustainable development are increasingly prominent. Biofuel ethanol, as a renewable energy source, is of great significance in addressing these issues. Promoting the rapid development of the biofuel ethanol industry requires the joint efforts of the society and the government, but there are differences in the social welfare effects of different subsidy modes and there are applicable conditions. Based on this, this paper uses Stackelberg game theory to compare the social welfare effects of R&D subsidy mode and production subsidy mode. The research results show that under certain conditions, both the R&D subsidy mode and the production subsidy mode can increase corporate profits, consumer surplus, and the level of social welfare. The optimal subsidy mode depends on the degree of R&D difficulty r and the slope b of the inverse demand function.

Specifically, when $1/2b < r < 3/4b$, the R&D subsidy mode and the production subsidy mode are inefficient from the perspective of social welfare, but biofuel ethanol companies can increase corporate profits by reducing R&D costs. When $3/4b < r < 1/b$, the production subsidy mode is inefficient, the R&D subsidy mode can improve the level of social welfare. When $r > 1/b$, both the R&D subsidy mode and the production subsidy mode are efficient, but the social welfare effect of the production subsidy mode is greater under the same conditions.

When the environmental effects of biofuel ethanol are relatively large, the optimal R&D subsidy rate increases with the increase in market demand potential; and when the environmental benefit of biofuel ethanol is small, the optimal R&D subsidy rate decreases as the market demand potential increases. The optimal unit production subsidy increases with the increase in market demand potential. When the difficulty of R&D is certain, the level of environmental benefits affects the rate of increase in the optimal unit production subsidy. In terms of social welfare, the production subsidy mode is inefficient under low R&D difficulty. In the case of high subsidies, the social welfare effects of both subsidy modes increase with the market demand potential. The difference is that the rate of increase is more pronounced under high environmental benefits.

The research model does not take into account the need to overcome key technology. In fact, the R&D subsidy mode may be a more direct and effective mode for the research and development of key technologies for biofuel ethanol at a specific stage. However, the conclusions of this study is still significant for the government in formulating subsidy policies and choosing subsidy modes. For example, subsidy can be eliminated for biofuel ethanol, which uses grain as the main raw material, because the technology is matured and research and development are less difficult. For non-food biofuel ethanol with moderate research and development difficulty, production subsidies can be canceled and R&D subsidies can be appropriately increased. The future development of cellulose biofuel ethanol requires production subsidies, due to its immature technology and difficult R&D. R&D subsidies could also be adopted at some key phases, mainly through market needs, in order to promote technological innovation.

It should be pointed out that the analysis in this paper is based on certain research hypotheses and may not be very consistent with reality. However, from the results of the research, R&D difficulty coefficient and the slope of the inverse demand function are important factors affecting the government's choice of the optimal subsidy mode. In addition to these two key factors, the optimal subsidy (rate) is also affected by the market demand potential and the increase in environmental benefits. Therefore, further research based on the actual data of the biofuel ethanol industry and market in China can be conducted.

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