Research Article

China’s Shale Gas Development Subsidy Analysis and Optimization considering Resource Endowment Characteristic

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The currently implemented indiscriminate subsidy policy in China is difficult to provide effective incentives for a firm’s investment behavior because it does not take into account the differences in resource characteristics. Thus, this paper puts forward a type of differentiated subsidy that considers resource conditions, consisting of a basic guaranteed subsidy and a variable incentive subsidy. First, from the perspective of the economic efficiency of enterprises, the amount of basic subsidy required by enterprises is calculated by the discounted cash flow method. Then, from the government’s perspective, a variable incentive subsidy amount is calculated by establishing an expectation benefit maximization function using principal-agent theory. The case application shows that due to the superior resources and development conditions of the Fuling block, it requires a significantly smaller subsidy amount than the Weiyuan block which verifies the need to consider regional differences in the design of shale gas development subsidies.

1. Introduction

With the growing global economy and increasing environmental awareness, natural gas, as a relatively clean resource in fossil energies, has been more preferred at the current circumstance that we are still unable to fully get rid of the reliance on fossil energy [1, 2]. It is reported that the growth of global primary energy consumption in 2019 is only half compared to 2018, but the proportion of natural gas consumption has reached its highest level ever (24.2%). In 2020, China’s disposable energy consumption reaches 1455 billions Joules, becoming the highest in the world. Of this, natural gas consumption accounts for about 8.4% and is on a year-on-year upward trend. Due to the widening gap between natural gas supply and demand, and the energy security concerns arising from high dependence on imported natural gas, China must vigorously develop domestic unconventional natural gas. In March 2023, the National Energy Administration announced the “Action Plan for Accelerating the Integration and Development of Oil and Gas Exploration and New Energy,” which calls for the continued promotion of the transformation and upgrading of the energy production and supply structure and the increase in the supply of new energy. As a member of new energy, shale gas will grow in potential and importance with each passing day [3]. Coupled with the success of the shale gas revolution in the U.S.A., this undoubtedly stimulates the Chinese government to pay attention to the development of the shale gas industry.

China is currently one of the most successful countries in the world in achieving commercial-scale development of land-phase shale oil, with major discoveries of land-phase shale oil in the Ordos Basin, Junggar Basin, Songliao Basin, Bohai Bay Basin, Qaidam Basin, Tarim Basin, etc. (Figure 1). Industrial breakthroughs and rapid development of marine shale gas have been achieved in the Sichuan Basin...
and its periphery, and by the end of 2021, there were eight cumulative proven shale gas fields with proven geological reserves of $2.74 \times 10^{12} \text{ m}^3$ in southern China [4]. It is generally agreed that China’s shale oil and gas resources have great potential and are a realistic strategic replacement area for conventional gas, but future exploration and efficient development still face many challenges, mainly in the following areas: (1) the results of resource potential and economic evaluation of shale gas vary widely, and there is still a large uncertainty in the optimum selection of favorable areas. An evaluation method that integrates shale gas enrichment control factors with multiple disciplines is expected to solve this problem [5]. (2) Compared with North America, the thickness of high-quality shale gas reservoirs in China is relatively small, the degree of tectonic transformation is strong, the continuity of the “sweet spot” is poor, and the cost and difficulty of construction are high. Long-term support and emphasis on basic research will be important factors for the success of shale oil and gas in China. (3) The U.S. shale oil and gas experienced losses for more than a decade before realizing record cash flows and profits due to the oil price spike in 2022, so the country should adhere to its policy of subsidizing shale gas and introducing fiscal incentives and tax support policies for shale oil and gas to promote the development of the shale oil and gas industry [6].

1.1. Shale Gas Development Economic and Social Benefits. Shale gas development is both a rational use of limited resources and will bring certain external benefits.

First of all, shale gas wells are suitable for large-scale commercial use because of their high gas production capacity, long gas production time, and stable gas supply, making shale gas an economically valuable mineral resource [7, 8]. Generally, the economic value of shale gas resources is influenced by their resource endowment, exploitation technology, prices, government policies, and other economic conditions [9].

Secondly, with the intensification of the domestic natural gas supply shortage situation, shale gas development and utilization have also eased the pressure of the gradually increasing shortage of natural gas to a certain extent, reflecting the important strategic significance of shale gas resources. As a major consumer of coal, China has produced large amounts of methane during coal mining, which will have an incalculable impact on the greenhouse effect. Therefore, the effective exploitation of shale gas resources is of great importance to suppress the greenhouse effect and protect the environment. Then, the area to which the shale gas resources belong will generate industrial agglomeration effects due to the development of shale gas, which will affect the quality of local production and life. As a huge system project, the labor force required for the whole industry chain and the consequent production and consumption will have a significant impact on the economic level and local tax revenue of a region [10, 11]. In summary, the development and utilization of shale gas will generate significant positive externalities.

Therefore, to achieve the goal of sustainable development of the shale gas industry, it is necessary to take into account both the economic benefits and the externality impacts of shale gas development.

1.2. China’s Shale Gas Policy Introduction. The U.S.A. has been encouraging the development of unconventional

![Distribution of major shale gas fields in China](image)
energy since the 1970s, and the Energy Windfall Act of 1980, which extended the tax incentives for several times without a subsidy period, has greatly stimulated the shale gas industry and contributed to the rapid development of shale gas [12]. Since 2004, the U.S.A. has spared no effort to invest heavily in unconventional gas exploration and recovery technologies, including shale gas, over a long period of time. The success of the U.S. shale gas revolution further demonstrates the importance of government investment in the development of this industry [13, 14].

In 2010, China successfully fractured its first shale gas well and obtained industrial gas flow, and the National Energy Administration announced that the central government should provide subsidies to shale gas exploitation enterprises. Shale gas has drawn increasing investment as an unconventional primary resource to renovate the global energy market [15, 16]. In particular, the implementation of the shale gas subsidy policy has set off a flurry of academic discussions [17].

China officially subsidized shale gas development in 2012 and has already experienced a decade-long history so far. The subsidy standard has been gradually reduced from the initial 0.4 RMB/m³ (2012-2015) to 0.3 RMB/m³ (2016-2018) and 0.2 RMB/m³ (2019-2020), even more so in 2019. [18, 19]. With the flexible application of government funds, there are a variety of allowance options that have emerged. But most researchers believe that direct production subsidy is by far the most effective economic incentive for shale gas development [20–22]. And as a capital-intensive and technology-intensive industry, these scrimpy subsidies are undoubtedly changing the investment behavior of some shale gas developers.

According to the Bureau of Energy Statistics, China’s shale gas production has surged year-by-year for the past decade, with growth slowing in the last two years [23]. Presumably, the substantial increase in output is inseparable from the support of the government’s fiscal policies over the last decades [24, 25]. Nevertheless, the effectiveness of subsidies remains a contentious issue. Due to China’s natural gas market mechanism and the complicated geological conditions of shale gas resources, the implementation of the policy has been far less effective than expected, and some enterprises have failed to enjoy such benefit [26].

In 2019, the Treasury Department of China announced that the fixed subsidy quotas were abolished and replaced by “ladder subsidy,” which states that the greater the contribution made by the enterprise to increase production, the higher the amount of subsidies enjoyed. Although this subsidy approach can enhance the competitiveness of enterprises in unconventional gas production and play a certain role in incentivizing subsidies, it does not take into account the long-term perspective of the balanced development of China’s shale gas industry. In addition, developers in areas that have invested heavily in exploration are likely to suffer losses in the development process if subsidies are eliminated or significantly reduced due to production issues [27]. In this case, a targeted and adjustable subsidy policy will be able to effectively stimulate corporate investment while being more suitable for the healthy and sustainable development of shale gas in China.

1.3. Research Topic and Literature Review. With the wave of the shale gas revolution sweeping the world, the scale development of China’s shale gas industry has experienced quite a few bumps in the road, especially the shale gas subsidy policy, which has been a matter of debate. With the rapid growth of shale gas production and the increasing financial pressure on the central government, it is inevitable that the shale gas subsidy policy will enter a phase of gradual reduction and cancellation.

Shale gas is a scarce resource, and if it is continuously given undifferentiated subsidies, it will send the wrong signal to the market, so that the limited subventions flow preferentially to high-quality resources and even to profitable projects, while the relatively poor resources have been delayed in entering the exploitation process due to insufficient funds [28]. This phenomenon has led to an extreme imbalance in the development of shale gas in China, which would go against the development strategy of sustainable energy development in our energy regulations [29, 30]. Meanwhile, the intended effect of the preferential policy has been greatly reduced. In this circumstance, the comprehensive shale gas subsidy policy with full coverage will not be suitable anymore. In this article, we mainly explored how to distribute the subsidy accurately in different regions.

As for the existing literature, most of the studies on shale gas policies in China are done at a macro level. Gong and Hu [31] analyzed the strengths, weaknesses, opportunities, and threats of shale gas development in China, emphasizing that policy support was an advantage. Zhang et al. [32] analyzed the barriers affecting the sustainable development of shale gas in China and agreed with the view that the lack of government support and guidelines was the most relevant barrier. Zhou [33] conducted an in-depth study on the shale gas production-transport-consumption system dynamics model to simulate fiscal policy scenarios, and the results showed that the shale gas-related policies implemented now have a certain lag. However, due to the rapid development of China’s shale gas industry, some traditional study methods are not suitable for the current situation. In the first few years of shale gas development in China, production and financial data were kept strictly confidential, and researchers were unable to obtain microscopic production data, let alone conduct detailed studies. However, after several years of effort, the number of shale gas projects in China has increased significantly, and the related data from gas-producing regions have provided a detailed database for microlevel studies.

In terms of research methods, Zhao et al. [34] summarizes the literature on oil and gas subsidies and their effects; explains the relationship between prices, subsidies, taxes, and recoverable reserves from a firm’s perspective; and examines the impact of four types of subsidies on prices, costs, risks, and cash flows. We refer to Zhao’s cash flow analysis to estimate the economic benefits incurred by companies in developing shale gas and explain from a company’s perspective whether they need a subsidy and how the amount of the basic guarantee subsidy is determined. Since another participant in subsidy behavior is the government, then it is essential to analyze the role of subsidies from the
government’s perspective. Yan [35] analyzes the principal-agent relationship among farms and the government, constructs a benefit distribution mechanism that can maximize stakeholder interests and land use efficiency, motivates participants, and ensures the smooth implementation of the policy. Referring to the principal-agent theory, we investigate the optimal design of a variable subsidy amount that can effectively motivate enterprises to invest under the condition of government financial permission from both government and enterprise perspectives.

Most studies on China’s shale gas subsidy policies are too general and superficial. Some studies on the economics of shale gas development in China have focused on economic feasibility, concluding that shale gas development requires strong and sustained subsidies [36]. Yang et al. [37] argued that for every 0.1 RMB/cubic meter increase in shale gas fiscal subsidies, the internal rate of return of companies could be increased by 0.8% to 1.5%. A generous amount of allowance can play an effective motivational role in firms’ decision; however, with the rapid growth of shale gas production in China, an excessively high subsidy level will increase the financial burden on the authorities and reduce the efficiency of capital allocation [38]. In recent years, experts have put forward site-specific views on shale subsidy amounts [39]. Liu [40] pointed out that the resource characteristics and exploitation conditions vary from block to block, and the indiscriminate production subsidy has made the limited subventions flow preferentially to high-quality resources and even to profitable projects, while the relatively poor resources have been delayed in entering the exploitation process due to insufficient funds. Bai [41] stated that the difficulty factor of shale gas production growth varies from block to block, and for blocks with higher development potential, the subsidy amount can be adjusted appropriately to increase the production growth rate of shale gas. Liu [42] pointed out that the fixed subsidy policy is not conducive to increasing the incentive of enterprises to increase production, and the diminishing output effect makes it more expensive for enterprises to increase production, so the subsidy amount and shale gas potential have some correlations. China’s shale gas resources have irregular natural attributes in terms of endowment characteristics and development conditions, requiring reasonable government intervention to effectively mitigate and improve the “resource curse” phenomenon [33]. The benefits of deploying differentiated subsidies are obvious, but how to precisely adjust the subsidy amounts is the primary issue to be addressed in practice. At present, there is little relevant literature describing the qualitative and quantitative relationship between resource endowment and shale gas subsidy amount. Therefore, it is of innovative and great practical significance to introduce block resource endowment and development conditions as influencing factors in the construction of shale gas development subsidy models and to propose reasonable and effective subsidy incentives to promote the balanced and sustainable development of China’s shale gas industry.

In addition, most studies on the external benefits of shale gas consider that the positive externalities of shale gas as a relatively clean energy source are key drivers for its rapid development and should not be ignored. However, they do not analyze and quantify the social benefits of shale gas development target areas. The few studies that quantify the social benefits of these target areas do not analyze the local geographic and economic conditions [43, 44], nor do they measure the hidden income beyond the economic benefits generated by shale gas development in China. For this issue, we analyze the social benefits of shale gas development in detail and include them in the subsidy calculation model.

Based on the problems of nondifferential production subsidies and the principles of efficiency and equity in subsidy implementation, we propose the idea of implementing differentiated subsidies based on the characteristics of shale gas resource endowment. We propose to (1) calculate the economic value of shale gas development in China from the perspective of enterprises and analyze whether they need subsidies as well as the minimum guaranteed subsidy determination method and specific amount; (2) quantify the social benefits generated by shale gas development from the perspective of the government and determine the amount of variable incentive subsidies required for shale gas development by combining the classification of shale gas block types; and (3) use case analysis in gas-producing regions to further confirm whether the established subsidy model is reliable and valid.

The solution to this series of problems has important theoretical and practical significance. Firstly, it helps to optimize the theoretical research related to the formulation and implementation of the shale gas development subsidy policy system in China; secondly, as far as shale gas enterprises are concerned, the research on the subsidy policy can provide a decision basis for the future investment planning of enterprise leaders to obtain greater economic benefits. Finally, this study measures the amount of shale gas subsidies for different blocks, which not only helps stimulate the balanced development of shale gas in various types of blocks and enhances the total shale gas production but also provides data reference for the government’s fiscal expenditure budget to avoid inefficient and ineffective fiscal subsidies and maximize the high-speed and high-quality development of the shale gas industry.

2. Technical Route of the Subsidy Optimization Model

Government subsidies to enterprises need to consider a variety of factors. Scholars have found that the amount of subsidy is closely related to the region, the government’s own financial status, the degree of marketization, the technology level, and the size of the companies. This paper explores the design of differentiated subsidy amounts from the perspectives of two major stakeholders in shale gas development subsidy policies, the government and developers.

As the subject, the authorities have a primary goal of pushing forward the landing of projects, meanwhile, encouraging companies to increase production in new development zones and keep stable yield in old ones. In other words, its ultimate aim is to maximize the expected rewards, including
social benefits such as relieving China’s tight energy demand and ensuring the country’s energy security, as long as it is financially feasible. In contrast, as the object engaged in this policy, the enterprises aim to obtain as many grants as possible to maximize their own economic benefits.

To accommodate the dual objectives of the administration and the firms in terms of amount expectations, this paper adopts a measurement model combining basic and variable subsidies and transforms the fixed output-based subsidy value into a dynamically adjustable range in order to accommodate the needs of China’s complex and diverse resource endowment characteristics of shale gas.

First, considering the profitability of enterprises, the government judges whether a shale gas project passes the demonstration and evaluation based on the financial data reported by enterprises, such as construction period costs, operating costs, and revenues, and then calculate the minimum value of the government subsidy, that is, the basic subsidy. Secondly, from the expected revenue of the administration, the variable subsidy incentive intensity coefficient is set according to the characteristics of resource endowment and exploitation conditions of different types of shale gas blocks, and the variable subsidy value is measured using the principal-agent model. Finally, the sum of the minimum amount and the variable amount is the optimized subsidy. This adjustable differentiated subsidy can play different incentive roles for different types of shale gas blocks, which can improve the efficiency of financial funds while taking into account the fairness of policy implementation in different regions. The specific framework for constructing the differentiated subsidy model is shown in Figure 2.

3. Quantification of Basic Subsidy Quota

It is well known that shale gas companies make investment decisions based on the economics of the project. Liu [28] argues from a comparison of the economics of shale gas projects in the three demonstration areas that some target areas could be profitable even without subsidies. However, producers in some areas that are resource poor or difficult to develop may find it difficult to proceed without subsidies. That is, the firms need some basic subsidies to sustain drilling and production activities and to guarantee their basic rate of return needs in order to make the investment move and drive the project to the ground.

Shale gas development is a complex input-output process, and it is influenced by a variety of economic parameters. In this paper, we draw on Liu’s [28] research idea that whether the enterprise is profitable is the basic subsidy threshold, in other words. If the economic value is positive throughout its life cycle, it means that the enterprise does not need subsidies from external funds. If the economic value is negative, companies will not develop shale gas without subsidies.

3.1. Estimation of the Costs. For the shale gas development costs of companies, most experts agree that the predevelopment costs account for the largest share of the total investment, including surface engineering costs, drilling engineering costs, and fracturing engineering costs [22]. Others believe that in addition to taxes on shale gas in China, they also account for a nonnegligible part. In China, the main taxes for shale gas development projects are resource tax, corporate income tax, value-added tax, construction tax, and education surtax. Therefore, the total cost of shale gas development can be expressed by the following formula.

![Figure 2: Framework of the differentiated subsidy model.](image-url)
where $C_{all}$ indicates as the total cost of shale gas exploitation, $I_s$ represents the surface engineering fee, $I_d$ represents the drilling engineering cost, $I_f$ represents the fracturing engineering cost, $C_{opex}$ represents the operating expenditure, and $T_x$ represents the taxes.

3.2. Estimation of the Revenues. The revenues from shale gas development include sales revenues and subsidies for shale gas development from a corporate perspective. Therefore, the formula for calculating the income arising from shale gas exploitation is as follows:

$$R_{all} = r_c \times p \times Q + s_0 \times Q,$$

where $R_{all}$ represents the revenue from shale gas exploitation, which consists of sales revenue and subsidy revenue, $r_c$ represents the commodity rate of shale gas, $p$ represents the shale gas sales price, $s_0$ represents the basic subsidies of shale gas per unit of production, and $Q$ represents the shale gas production.

3.3. Economic Value Estimate Model. Discounted cash flow method, as a popular and useful measure of economic efficiency, provides a convenient and effective assessment of the sum of cash flow generated over the economic life of a project at a given discount rate [45]. In conjunction with the formulas for calculating the costs and the revenues of shale gas development already presented earlier, we can use Equation (3) to express the economic value of shale gas development.

$$E_{all} = \sum_{t=1}^{T} \frac{R_{all} - C_{all}}{(1 + r)^t},$$

where $E_{all}$ represents the total economic value of shale gas exploitation, $r$ is the discount rate, and $T$ is the evaluation period.

3.4. Results Analysis. Currently, only a few shale gas development areas in China have achieved commercial production and realized a production capacity of more than 1 billion cubic meters, including Sinopec’s Fuling target area in Chongqing, PetroChina’s Changning-Weiyuan target area in Sichuan Province and the Zhaotong target area in Yunnan Province. These three target areas are also national shale gas demonstration areas established by the National Development and Reform Commission in 2012. Given the ease of access to relevant data, this paper uses typical single wells in the Fuling and Weiyuan demonstration areas to measure the economic value of shale gas development in China.

3.4.1. Project Parameters and Financial Data. Considering that the economic life of a single well is generally 20-30 years, a construction period of 3 years and an operation period of 17 years are set. The actual occurrences related to the cash flow of the project from 2013 to 2020 are taken, and the cash flow-related indicators for 2021 and beyond are projected, as detailed in Tables 1–3.

3.4.2. Single Well Production Analysis. According to the revenue estimation formula, it can be seen that the production parameter $Q$ is an important factor affecting revenue from shale gas development [28]. Combined with the decreasing law of single wells year-by-year [46, 47], the shale gas production forecasts for the two blocks are shown in Figures 3 and 4.

3.4.3. The Basic Subsidy. The capital flows of the shale gas development project in 2016 were calculated as an example according to the net present value method to obtain the base subsidy $s_0$ for each year. The basic subsidies ($s_f$) of the two blocks in Table 4 are significantly different. Especially in the first year of the operation period, the basic subsidy of the Fuling block in 2016 is 1.03 RMB/m$^3$, and the Weiyuan needs 2.22 RMB/m$^3$ to meet the enterprise’s basic rate of return requirement. This is mainly due to the high cost of the construction period of shale gas development projects, coupled with the fact that the initial production revenue is not yet sufficient to cover the huge initial investment, and therefore, higher government subsidies are required to protect the basic interests of the enterprises. With the extension of the production period and the increase in cumulative production, the shale gas companies in the Fuling block will be able to meet their basic profitability needs without government subsidies in 2017 and beyond. In contrast, the subsidy factor for the Weiyuan block in 2018 and beyond is maintained at around 0.9 RMB/m$^3$ to ensure the profitability of the enterprises. This is mainly because the marginal cost during the operation period will gradually increase with the decreasing annual production, and the sales revenue caused by the production cannot cover the operating expenses, so a certain government subsidy is still required in the late stage of production to maintain the basic rate of return each year.

The basic subsidies required for the Weiyuan block are significantly higher than those for the Fuling block, which once again shows that the nondiscriminatory production subsidy is not applicable to shale gas companies on different blocks.

### Table 1: Parameters of shale gas development project.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Specific value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project period</td>
<td>Year</td>
<td>20</td>
</tr>
<tr>
<td>Construction period</td>
<td>Year</td>
<td>3</td>
</tr>
<tr>
<td>Operational period</td>
<td>Year</td>
<td>17</td>
</tr>
<tr>
<td>Annual production days</td>
<td>Day</td>
<td>330</td>
</tr>
<tr>
<td>Commodity rate</td>
<td>%</td>
<td>95</td>
</tr>
<tr>
<td>Scrap value of fixed assets</td>
<td>%</td>
<td>0</td>
</tr>
<tr>
<td>Depreciation method</td>
<td></td>
<td>Straight line</td>
</tr>
<tr>
<td>Added-value tax</td>
<td>%</td>
<td>9</td>
</tr>
<tr>
<td>Urban maintenance and construction tax</td>
<td>%</td>
<td>Fuling: 7; Weiyuan: 5</td>
</tr>
<tr>
<td>Education surtax</td>
<td>%</td>
<td>2</td>
</tr>
<tr>
<td>Resource tax</td>
<td>%</td>
<td>4.2</td>
</tr>
<tr>
<td>Corporate income tax</td>
<td>%</td>
<td>15 (before 2021); 25(after 2021)</td>
</tr>
<tr>
<td>Year</td>
<td>Construction period</td>
<td>Fracturing engineering costs</td>
</tr>
<tr>
<td>------</td>
<td>---------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td></td>
<td>Surface engineering costs</td>
<td>Drilling engineering costs</td>
</tr>
<tr>
<td>2013</td>
<td>1,292</td>
<td>1,788</td>
</tr>
<tr>
<td>2014</td>
<td>1,735</td>
<td>2,859</td>
</tr>
<tr>
<td>2015</td>
<td>854</td>
<td>3,243</td>
</tr>
<tr>
<td>2016</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td></td>
<td></td>
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<td>2018</td>
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<td>2019</td>
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<td>2020</td>
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<td>2022</td>
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<td>2025</td>
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<td>2026</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>2027</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>
Table 3: Capital flow statement of a shale gas well development project in the Weiyuan block (RMB million).

<table>
<thead>
<tr>
<th>Year</th>
<th>Surface engineering costs</th>
<th>Construction period costs</th>
<th>Fracturing engineering costs</th>
<th>Operation expenditure</th>
<th>Costs operating costs</th>
<th>Operating revenue</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Drilling engineering costs</td>
<td></td>
<td>Employee wages</td>
<td>Depreciation and depletion</td>
<td>Materials, fuel costs</td>
</tr>
<tr>
<td>2013</td>
<td>741</td>
<td>2,102</td>
<td>1,853</td>
<td>1,572</td>
<td>983</td>
<td>433.40</td>
</tr>
<tr>
<td>2014</td>
<td>953</td>
<td>2,615</td>
<td>1,646</td>
<td>1,984</td>
<td>1,121</td>
<td>451.00</td>
</tr>
<tr>
<td>2015</td>
<td>521</td>
<td>2,930</td>
<td>1,425</td>
<td>1,386</td>
<td>998</td>
<td>451.00</td>
</tr>
<tr>
<td>2016</td>
<td></td>
<td></td>
<td>1,245</td>
<td>1,251</td>
<td>870</td>
<td>433.40</td>
</tr>
<tr>
<td>2017</td>
<td></td>
<td></td>
<td>1,184</td>
<td>1,100</td>
<td>994</td>
<td>451.00</td>
</tr>
<tr>
<td>2018</td>
<td></td>
<td></td>
<td>992</td>
<td>936</td>
<td>713</td>
<td>293.15</td>
</tr>
<tr>
<td>2019</td>
<td></td>
<td></td>
<td>814</td>
<td>816</td>
<td>523</td>
<td>202.95</td>
</tr>
<tr>
<td>2020</td>
<td>—</td>
<td></td>
<td>564</td>
<td>589</td>
<td>325</td>
<td>166.87</td>
</tr>
<tr>
<td>2021</td>
<td>—</td>
<td></td>
<td>564</td>
<td>589</td>
<td>325</td>
<td>112.75</td>
</tr>
<tr>
<td>2022</td>
<td>—</td>
<td></td>
<td>564</td>
<td>589</td>
<td>325</td>
<td>67.65</td>
</tr>
<tr>
<td>2023</td>
<td>—</td>
<td></td>
<td>564</td>
<td>589</td>
<td>325</td>
<td>45.10</td>
</tr>
<tr>
<td>2024</td>
<td>—</td>
<td></td>
<td>564</td>
<td>589</td>
<td>325</td>
<td>40.59</td>
</tr>
<tr>
<td>2025</td>
<td>—</td>
<td></td>
<td>564</td>
<td>589</td>
<td>325</td>
<td>36.08</td>
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<td></td>
<td>564</td>
<td>589</td>
<td>325</td>
<td>31.57</td>
</tr>
<tr>
<td>2027</td>
<td>—</td>
<td></td>
<td>564</td>
<td>589</td>
<td>325</td>
<td>31.57</td>
</tr>
</tbody>
</table>
4. Quantification of Variable Subsidy Quota

After calculating the minimum subsidy required for shale gas producers to reach the break-even point, we also need to find the amount of subsidy that will effectively stimulate firms under the conditions of fiscal spending allowances. Obviously, the larger the subsidy, the more stimulating it will be for companies to make development decisions. The government, as the main body of policy implementation, needs to judge whether the behavior of enterprises is worthy of subsidies, that is, the determination of the upper limit of subsidies.

At this time, the government’s willingness to pay subsidies depends largely on whether the shale gas project will produce the benefits the government expects. The government is interested in the social benefits generated by shale gas development. Of course, the higher the economic benefits generated by a block with better resource conditions, the higher the social benefits will be. Thus, the high social benefits are tied to the endowment conditions of the block’s resources. As mentioned earlier, from the perspective of healthy and sustainable development, the government should impose different subsidy incentives for shale gas blocks with different resource conditions, so that the economic benefits obtained by companies investing in any block tend to be equitable by weakening the problem of inherent resource imbalance.

Therefore, when designing variable subsidy amounts, it is necessary to consider both resource endowment characteristics and social benefits and then analyze and quantify the quantitative relationship between the two parameters and the subsidy amount.

4.1. Estimating the Social Benefits. The view that shale gas development will bring about major social benefits to China is now shared by most scholars. First, although shale gas exploitation will also cause some environmental pollution, it is much cleaner than coal, which still accounts for about 60% of China’s primary energy. In addition, shale gas development can impact the local economy of a region. Tax revenues represent the direct benefits of shale gas development to governments. Job growth driven by shale gas projects can also directly represent the impact of shale gas development on the local economy. Finally, the development of shale gas can undoubtedly ease the tight supply and demand for natural gas in China and reduce China’s dependence on foreign gas. Therefore, the social benefits related to this paper focus on four aspects.

<table>
<thead>
<tr>
<th>Year</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuling block</td>
<td>1.03</td>
<td>-0.61</td>
<td>-0.17</td>
<td>0.24</td>
<td>-0.09</td>
</tr>
<tr>
<td>Weiyuan block</td>
<td>2.22</td>
<td>0.53</td>
<td>0.91</td>
<td>0.89</td>
<td>0.93</td>
</tr>
</tbody>
</table>
The benefits generated per cubic meter of shale gas can be considered in four main aspects: environmental benefit, national tax revenue, employment growth, and national energy security [48, 49].

(a) Environmental Benefit ($R_1$). Referring to Chang et al. [50] for the calculation of the environmental benefits of greenhouse gas reduction from shale gas production, $R_1$ is estimated to be 0.164 RMB/m$^3$.

(b) National Tax Revenue ($R_2$). The taxes paid for shale gas development projects in China mainly include value-added tax ($r_1$), resource tax ($r_2$), urban construction tax ($r_3$), education tax surcharge ($r_4$), and income tax ($r_5$). The total tax calculation formula is expressed as

$$R_2 = pQ \times (r_1 + r_2) + pQ \times r_1 \times (r_3 + r_4) + (pQ + S - C) \times r_5. \tag{4}$$

(c) Employment Growth ($R_3$). Given China’s high dependence on oil and gas, assuming that shale gas development directly increases the number of jobs, the employment income per unit of shale gas is expressed as $R_3 = P_j \times N_j$, in which $P_j$ refers to the amount of unemployment compensation, $N_j$ means the number of jobs provided per unit shale gas, 2-4 persons/m$^3$. For example, the unemployment basic allowance in Chongqing Municipality is 1050 RMB/month, based on which $R_3$ is considered to be 0.021 RMB/m$^3$.

(d) National Energy Security ($R_4$). Here, drawing on the algorithm for the contribution of coaled methane development to energy security proposed by Luo and Xia [51], it is believed that the energy security benefit $R_4$ produced by each cubic meter of shale gas is about 0.007 RMB/m$^3$.

4.2. Classification of Shale Gas Resource Types. The basic idea of differential subsidies is to classify the level of subsidies according to the differentiation of shale gas block characteristics, so it is necessary to analyze the relationship between the resource conditions and the amount of subsidy. Resource endowment and exploitation conditions are qualitative indicators with proven methods and findings for reference [52], on the basis of which we specify and quantify this key parameter.

4.2.1. Block Selection. Taking the Wufeng-Longmaxi formation as an example, five assessment units, including A, B, C, D, and E, are selected in combination with geographically flat areas, 12 key indexes are filtered for evaluation, and the data are shown in Table 5 [46].

4.2.2. Weight Determination. The subjective weight $w_{ij}$ and objective weight $w_{kj}$ are determined by the reformed analytic hierarchy process and entropy method, respectively, and the combination weight is calculated by

$$w_j = \frac{w_{ij} w_{kj}}{\sum_{j=1}^{n} w_{ij} w_{kj}} (j = 1, 2, \cdots, 12). \tag{5}$$

4.2.3. Gray Correlation, Euclidean Distance, and Relative Closeness [53]. First, the original data are normalized and multiplied by the integrated weights to compute the weighted normalization matrix $(z_{ij}) \times n$. Next, the gray correlation $r_i^*$ and $r^*_j$ and Euclidean distance $d_i^*$ and $d_j^*$ of each block with positive and negative ideal solutions are measured according to Equations (6)–(8); then, the gray correlation and Euclidean distance are dimensionless, and finally, the relative closeness $C_i^*$ is obtained. The related data are shown in Table 6.

$$r_i^* = \frac{1}{n} \sum_{j=1}^{n} \min \left\{ \frac{z_{ij} - z_{ij}}{|z_{ij} - z_j^*| + \rho \max |z_{ij} - z_j^*|} \right\}$$

$$r_j^* = \frac{1}{n} \sum_{i=1}^{n} \min \left\{ \frac{z_{ij} - z_{ij}}{|z_{ij} - z_i^*| + \rho \max |z_{ij} - z_i^*|} \right\} \tag{6}$$
4.3. Variable Subsidy Modeling Based on Resource Characteristics

4.3.1. Problem Description and Model Hypotheses. Usually, the policy formulation does not affect the enterprises as well as the government in isolation. The government entrusts its energy needs to the developer in the trade, and conversely, the developer achieves the government’s goals as an agent based on the development of shale gas. The government’s subsidy decisions directly determine the company’s investment behavior, and the company’s development step also affects the government’s future revenues. The two parties form a principal-agent relationship through the project contract, with the government department as the principal and the enterprise as the agent. (Figure 6).

However, in the process of policy-making, there is a game and information asymmetry between the government and the developer in the principal-agent relationship for the shale gas development subsidies [54]. First, the

Table 6: Gray correlation, Euclidean distance, and relative closeness.

<table>
<thead>
<tr>
<th>Block</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray correlation of positive ideal solution</td>
<td>0.1002</td>
<td>0.6544</td>
<td>0.6437</td>
<td>1.0000</td>
<td>0.7102</td>
</tr>
<tr>
<td>Gray correlation of negative ideal solution</td>
<td>1.0000</td>
<td>0.8180</td>
<td>0.8149</td>
<td>0.1235</td>
<td>0.8755</td>
</tr>
<tr>
<td>Euclidean distance of positive ideal solution</td>
<td>1.0000</td>
<td>0.8784</td>
<td>0.8126</td>
<td>0.1127</td>
<td>0.9084</td>
</tr>
<tr>
<td>Euclidean distance of negative ideal solution</td>
<td>0.1100</td>
<td>0.4861</td>
<td>0.5576</td>
<td>1.0000</td>
<td>0.4224</td>
</tr>
<tr>
<td>Relative closeness</td>
<td>0.1984</td>
<td>0.4020</td>
<td>0.4247</td>
<td>0.8944</td>
<td>0.5150</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
    d_i^+ &= \sqrt{\sum_{j=1}^{n} (z_{ij} - z_i^+)^2}, \\
    d_i^- &= \sqrt{\sum_{j=1}^{n} (z_{ij} - z_i^-)^2}, \\
    C_i^+ &= \frac{T_i^+}{T_i^+ + T_i^-} = \frac{mR_i^+ + nD_i^-}{(mR_i^+ + nD_i^-) + (mR_i^- + nD_i^+)},
\end{align*}
\]

where \(|z_{ij} - z_i^+| \) and \(|z_{ij} - z_i^-| \) denote the absolute difference between the positive and negative ideal solutions and the sample, respectively. \(\rho\) represents the resolution factor. \(R_i^+\) and \(R_i^-\) are the dimensionless values of the correlation between the block and the positive and negative ideal solutions \((r_i^+\) and \(r_i^-\), respectively. \(D_i^+\) and \(D_i^-\) indicate the dimensionless values of the Euclidean distance \((d_i^+\) and \(d_i^-\)). \(m\) and \(n\) lies between 0 and 1, and both are usually taken as 0.5.

4.2.4. Determination of the Correlation Coefficient \((a)\). The relative closeness \(C_i^+\) reflects the degree of approximation between the block and the ideal solution. The larger the value of \(C_i^+\), the better the block is, representing the higher value of the correlation coefficient between the resource conditions and social benefits \((a)\). Conversely, the smaller the value of \(C_i^+\), the worse the block is. Hence, the relationship between \(a\) and \(C_i^+\) is expressed as a linear segmentation function.

\[
a = \begin{cases} 
1 & C_i^+ \leq 0.2, \\
\frac{5}{3} C_i^+ - \frac{4}{3} & 0.2 < C_i^+ < 0.8, \\
0 & C_i^+ \geq 0.8.
\end{cases}
\]

The blocks are classified into four types depending on the value of \(a\). Figure 5 shows that gold type refers to blocks with excellent resource endowment and development environment, which shows a large relative closeness \((C_i^+ > 0.8)\), as in the evaluation unit D. The blocks are quite productive and profitable even without subsidies \((a = 0)\).

Sunrise type has better quality in the resource but poor in exploitation, or average resource characteristic but favorable exploitation conditions, \(0.5 < C_i^+ < 0.8\), as in E. Potential blocks mean blocks with good resource conditions, \(0.2 < C_i^+ < 0.5\), such as B or C. These two types are a strong guarantee for increased shale gas production and a key target for government support, but the developers have expressed little enthusiasm because of low output or insufficient technology at present.

Sunset type is not suitable for excessive subsidies \((a = 1)\) due to barren resource and difficult development conditions that prevent the blocks from generating higher returns, \(C_i^+ < 0.2\), as in A.
government, which aims to improve its own expected benefits by formulation of a subsidy policy, will try to reduce its fiscal expenditures with the aim of obtaining the maximum output with the least input, while the ultimate goal of enterprises is to choose the decision to maximize the possibility of obtaining subsidies, to ease their own production costs for the purpose of investment and development, and to obtain greater profits. [4, 55]. These two expectations of the subsidy amount are mutually exclusive in terms of direction. Second, developers are dealing with shale gas blocks with complex conditions of the blocks and will only choose to invest if the business is conducted according to the capacity only. At present, China’s shale gas subsidies are uniform for companies in different regions, but in the actual development process, different blocks face different risk information. Therefore, compared to the government, enterprises have more detailed information about the resource endowment and exploitation conditions of the blocks and will only choose to invest in production if their own interests can be protected. In contrast, the government obtains information from enterprises’ collated project reports and financial statements, and the material has the characteristics of generality and hysteresis [56, 34].

Combining the basic model of principal-agent theory and the construction-operation status of shale gas projects, the following hypotheses are made:

1. The government, as an entrusting party, is risk neutral. As an agent, enterprises behave as risk averse.
2. Both the government and the enterprise are rational persons, the government’s goal is to maximize desired benefits, and the business’s target is to maximize economic benefits.
3. The degree of effort of the enterprise is defined as $e$.
4. The cost of business operations is the sum of fixed and variable costs

$$C = C_0 + C_e + C_p$$  \(10\)

where $C_0$ indicates fixed cost. Variable costs consist of effort cost ($C_e$) and risk cost ($C_p$), which are, respectively, represented by quadratic function as follows: $C_e = c^2e^2/2$ and $C_p = \rho \sigma^2/2$, $c$ is the effort cost coefficient, $\rho$ is the risk aversion coefficient, and $\sigma^2$ is the standard value of random variable variance.

5. The economic benefit $G$ and social benefit $Bs$ generated in the shale gas development process are explained as follows:

$$G = pQ,$$  \(11\)

where $p$ is the natural gas sales price, $Q$ is the shale gas production, expressed as a linear function: $Q = Q_0 + k\epsilon$, where $k$ is the correlation index between the degree of effort and shale gas production. The commodity rate $r$, for shale gas represents the ratio of shale gas sales to production, which in China is set at 90%. Since it approximates a constant, we ignored it here.

$$B_s = qe + \epsilon.$$  \(12\)

In this expression, $q$ indicates the correlation coefficient between the effort level and the social benefit, that is, the social benefit per unit of effort. In this paper, we define it as the social benefit coefficient. $\epsilon$ obeys normal distribution with $\epsilon \sim N(0, \sigma^2)$.

6. $\beta$ denotes the variable subsidy incentive intensity coefficient.

7. The correlation coefficient between resource conditions (resource endowment and exploitation conditions) and expected social benefits is set to $a$.

4.3.2. Model Building and Solving

1. Government’s Revenue Function. The government’s revenue is related to the output of shale gas projects and the expenditure for financial subsidies, which is shown as the following formula:

$$X = G + B_s - S.$$  \(13\)

In the principal-agent relationship for contract payments, the subsidy scheme requires a trade-off between the government and shale gas developers. Theoretical studies show that linear allocation achieves an optimal balance between risk aversion and revenue objectives in the presence of information asymmetry [57]. Usually, governments set a standard point for incentives, which in this paper is assumed to be the underlying social benefit and is expressed in the following as a function: $B_s = q_0 \epsilon_0$.

$a_0$ is identified as the resource endowment and mining conditions of the shale gas blocks at the basic level of effort ($\epsilon_0$), and then the subsidy formula is refined as follows:

$$S = (s_0 + s_1)Q = \left[s_0 + \beta(n_1(qe - q_0 \epsilon_0) + n_2(\epsilon - a_0 \epsilon_0))\right]Q.$$  \(14\)
In this function, the subsidy amount is divided into two parts: the basic subsidy \( s_0 \) and the variable subsidy \( s_1 \). The weights of the social benefit coefficient and the resource conditions on \( \beta \) are represented as \( n_1 \) and \( n_2 \), respectively, and satisfy the condition: \( n_1 + n_2 = 1 \).

According to hypothesis (1), the government’s expected utility function is the revenue function.

\[
E(X) = pQ + qe - [s_0 + \beta(n_1(qe-q_0e_0) + n_2(\alpha\text{-}a_0e_0))]Q.
\]

(15)

(2) Enterprise’s Revenue Function. Enterprise profit is mainly associated with sales revenue, government allocations, and project-related expenses. Its calculation formula is as follows:

\[
Y = G + S - C.
\]

(16)

And then, the enterprise’s revenue function is expressed as follows:

\[
E(Y) = pQ + [s_0 + \beta(\alpha\text{-}a_0e_0)]Q - C_0 - \frac{1}{2} ce^2 - \frac{1}{2} \rho \sigma^2.
\]

(17)

(3) Objective Function and Constraints. With the government as the subject, the objective function is established with its expected revenue, which appears as shown below.

\[
\max E(X) = pQ + qe - [s_0 + \beta(n_1(qe-q_0e_0) + n_2(\alpha\text{-}a_0e_0))]Q.
\]

(18)

The conflicting interests between the authorities and the company form the constraints, as indicated in the following equation:

\[
(I)\left[p + s_0 + \beta(n_1(qe-q_0e_0) + n_2(\alpha\text{-}a_0e_0))]Q - C_0 - \frac{1}{2} ce^2 - \frac{1}{2} \rho \sigma^2 \geq Y, \right.
\]

\[
(IC)\left[p + s_0 + \beta(n_1(qe-q_0e_0) + n_2(\alpha\text{-}a_0e_0))]Q - C_0 - \frac{1}{2} ce^2 - \frac{1}{2} \rho \sigma^2 \right.
\]

\[
\geq pQ + [s_0 + \beta(n_1(qe-q_0e_0) + n_2(\alpha\text{-}a_0e_0))]Q
\]

\[
- C_0 - \frac{1}{2} ce^2 - \frac{1}{2} \rho \sigma^2.
\]

(19)

The participatory constraint (IR) refers to the choice of behavior (e) by the enterprise that is more profitable than the average for the same industry. The incentive compatibility constraint (IC) means that the returns got by the company for completing the project at the chosen level of e are higher than those received at any other effort (e').

With the government incentives, the firms select the degree of effort based on financial calculations so as to maximize their profits. In this case, the effort level is considered to be the maximum value while satisfying the following conditions:

\[
e\arg\max Y = [p + s_0 + \beta(n_1(qe-q_0e_0) + n_2(\alpha\text{-}a_0e_0))]Q - C_0 - \frac{1}{2} ce^2 - \frac{1}{2} \rho \sigma^2,
\]

(20)

\[
\frac{\partial Y}{\partial e} = 0, \quad \frac{\partial^2 Y}{\partial e^2} < 0.
\]

(21)

Through the above steps, the formula for calculating the effort level is derived as follows:

\[
e = \frac{pk + \beta(n_1q + n_2a)}{c}.
\]

(22)

For convenience, k is replaced by q, which assumes that the relationship between effort level and shale gas production is consistent with the correlation coefficient between effort level and social benefit output. In addition, the companies need to reach a certain level of behavioral performance for further excitement. Hence, the Lagrangian function is built.

\[
L(\beta) = \rho(Q_0 + k) + \rho\sigma - \rho\epsilon + \rho\sigma + \beta(n_1(qe-q_0e_0) + n_2(\alpha\text{-}a_0e_0))
\]

\[
\cdot Q + \lambda[p(Q_0 + k) + s_0 + \beta(n_1(qe-q_0e_0) + n_2(\alpha\text{-}a_0e_0))]
\]

\[
\cdot Q - C_0 - \frac{1}{2} ce^2 - \frac{1}{2} \rho \sigma^2.
\]

(23)

Substituting Equation (14) into the above, the first order derivative of the Lagrangian function with respect to \( \beta \) leads to the following equation: when \( \lambda = \frac{(n_1q + n_2a)(pq + 1)}{(n_1q + n_2a)^2 + \rho \sigma^2} \),

\[
\beta = \frac{(n_1q + n_2a)(pq + 1)}{(n_1q + n_2a)^2 + \rho \sigma^2}.
\]

(24)

It is clear that \( \beta \) is negatively correlated with \( \sigma^2 \), \( c \), and \( \rho \), while \( p \) has a positive relation with \( \beta \), and the correlation of \( q \) and \( a \) with respect to \( \beta \) is uncertain.

4.4. Case Analysis. Based on the case background mentioned in Section 3, this paper analyzes and compares the amounts of variable subsidy required for the two blocks.

4.4.1. Resource Endowment and Exploitation Conditions. The representative geological parameters and development conditions parameters of shales in the Wufeng-Longmaxi formation in the Fuling and Weiyuan shale gas demonstration areas were selected through literature statistics of exploration data from multiple wells [4], as shown in Table 7. The figures in parentheses are taken as the average values from the shale gas wells (see Section 3.4 for project background), which are selected to calculate the correlation coefficients.
between the resource conditions and the social benefits of the block.

The relative closeness of the Fuling and the Weiyuan is 0.8944 and 0.5150, respectively, according to the above shale gas resource classification method. Combined with the segmentation function (Equation (9)), the correlation coefficient between the resource conditions and social benefits of the two blocks are 0 and 0.525, respectively.

### 4.4.2. Determination of Each Parameter of the Principal-Agent Model

1. **Social Benefit Coefficient**. The method of quantifying the social benefits of shale gas development has been described in Section 4.1. Here, the environmental benefit generated per cubic meter of shale gas ($R_1$) is 0.164 RMB/m$^3$.

   Referring to the data on the capital flow of shale gas projects in the Fuling block in Chongqing and the Weiyuan block in Sichuan Province, the tax revenue per unit of shale gas produced ($R_2$) is shown in Table 8. The total tax revenue in the Fuling block is RMB 0.403/m$^3$, and in the Weiyuan block is RMB 0.346/m$^3$.

   Based on the unemployment subsidy standard (Chongqing: RMB 1050/month per person; Weiyuan: RMB 264/month per person), the employment growth benefit ($R_3$) from shale gas development in Chongqing is calculated to be about RMB 0.021/m$^3$; and about RMB 0.005/m$^3$ in Weiyuan, Sichuan.

   The energy security benefit ($R_4$) produced by each cubic meter of shale gas is considered to be 0.007 RMB/m$^3$.

   Therefore, the social benefit coefficient in the Fuling block is RMB 0.595/m$^3$. Similarly, the Weiyuan block is RMB 0.522/m$^3$.

2. **Enterprise's Effort Cost Coefficient ($c$)**. The effort cost incurred per cubic meter of shale gas production can be expressed as $c = \varepsilon \times (\theta_1 + \theta_2)$, where $\theta_1$ and $\theta_2$ represent the annual employee salaries and annual overhead expense, respectively. $\varepsilon$ ranges from 0 to 1 and is taken here as 0.5. Based on the profile of a shale gas well project in the Fuling block mentioned in Section 3.4, the annual employee salary cost during the operation phase is 38.84 million. The annual overhead costs are $32.57 million. Therefore, the effort cost factor incurred per shale gas production is RMB 0.516/m$^3$. The diminishing effect of production can lead to a rapid increase in effort costs as the operation proceeds.

3. **Shale Gas Price ($p$)**. It is considered that the price of shale gas is influenced by the external environment such as the international market and political and economic environment and has little relationship with the difference between shale gas blocks, so it is set at 2 RMB/m$^3$ here.

4. **Risk Aversion Factor for Companies ($\rho$)**. As the builder and operator of shale gas development projects, expecting better economic benefits will behave as risk averse. The range of $\rho$ is generally from 1 to 4. Considering the reasonableness of the values, the risk aversion factor in this paper is assumed to be 2.

5. **Weights of Impact Factors ($n_1$ and $n_2$) on the Variable Subsidy Stimulus Intensity Coefficient**. Economic profits are intrinsically linked to social performance. Given that the minimum subsidy value is calculated from the shale gas yield profit that already contains the social performance, it is inevitable that the social benefits will be overestimated if the impact weight of both parameters ($n_1$ and $n_2$) are set to 0.5. To ensure the reliability of the calculation, $n_1$ and $n_2$ are assumed to be 0.3 and 0.7, respectively.
In contrast, shale gas companies in the Weiyuan block need additional subsidy stimulation measures, so that economic goals of enterprises are easier to achieve with the endowment and exploitation conditions of the block, and the block has high shale gas output due to the better resource endowment and exploitation conditions of the block. This indicates that the Fuling block has high shale gas price, while the value in the Weiyuan block is significantly higher than that in the Fuling block. This indicates that the Fuling block has high shale gas price, while the value in the Weiyuan block is significantly higher than that in the Fuling block. This is consistent with the statements reported by enterprises to protect their internal revenue, and then adjust the subsidy according to its own expected benefit maximization.

4.5. Model Sensitivity Analysis. There are many factors affecting the subsidy amount for shale gas development, and uncertainty analysis is used to identify sensitive factors affecting the variable subsidy amount and determine the degree of their influence, which helps to analyze possible effective control measures to reduce the risk of uncertainty and improve and enhance the reasonableness of the subsidy amount.

Table 9: Parameter values of the principal-agent model.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Fuling block</th>
<th>Weiyuan block</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social benefit coefficient, q</td>
<td>0.595</td>
<td>0.522</td>
</tr>
<tr>
<td>Correlation coefficient between resource conditions and expected social benefits, a</td>
<td>0</td>
<td>0.525</td>
</tr>
<tr>
<td>The weight of social benefit coefficient on β, n₁</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>The weight of resource conditions on β, n₂</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Shale gas price, p</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Enterprise’s effort cost coefficient, c</td>
<td>0.516</td>
<td>0.572</td>
</tr>
<tr>
<td>The risk aversion coefficient, ρ</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>The standard value of random variable variance, σ²</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 10: Variable subsidy and optimized subsidy coefficients.

<table>
<thead>
<tr>
<th>Year</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuling: s₁</td>
<td>0.07</td>
<td>0.08</td>
<td>0.06</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>sₙ + s₁</td>
<td>1.10</td>
<td>-0.53</td>
<td>-0.11</td>
<td>0.31</td>
<td>-0.02</td>
</tr>
<tr>
<td>Weiyuan: s₁</td>
<td>0.40</td>
<td>0.30</td>
<td>0.25</td>
<td>0.24</td>
<td>0.23</td>
</tr>
<tr>
<td>sₙ + s₁</td>
<td>2.62</td>
<td>0.83</td>
<td>1.16</td>
<td>1.13</td>
<td>1.16</td>
</tr>
</tbody>
</table>

Bringing the parameter values of the principal-agent model in Table 9 into Equation (24), the variable subsidy incentive intensity coefficients for the two blocks in 2016 are calculated as follows:

Fuling: \[ \beta = \frac{(n₁q + n₂)(pq + 1)}{(n₁q + n₂)^2 + \rho cσ^2} = \frac{(0.3 \times 0.595)(2 \times 0.595 + 1)}{(0.3 \times 0.595)^2 + 2 \times 0.516} = 0.37, \]

Weiyuan: \[ \beta = \frac{(n₁q + n₂)(pq + 1)}{(n₁q + n₂)^2 + \rho cσ^2} = \frac{(0.3 \times 0.522 + 0.7 \times 0.525)(2 \times 0.522 + 1)}{(0.3 \times 0.522 + 0.7 \times 0.525)^2 + 2 \times 0.572 \times 1} = 0.76. \]

\[ \beta \in (0, 1) \] meets the set range, so the model validation is reasonable.

According to the calculated variable subsidy incentive intensity coefficients, the variable subsidy (s₁) and the optimized subsidy factor (s) can be obtained by combing with Equation (6), the results are shown in Table 10.

The variable subsidy (s₁) factors in the Fuling block are small and stable at about 0.07 RMB/m³ from 2016 to 2020, while the value in the Weiyuan block is significantly higher than that in the Fuling block. This indicates that the Fuling block has high shale gas output due to the better resource endowment and exploitation conditions of the block, and the economic goals of enterprises are easier to achieve without additional subsidy stimulation measures, so that enterprises will spontaneously invest in development. In contrast, shale gas companies in the Weiyuan block need some subsidy stimulus to actively invest and develop the shale gas industry.

In terms of the integrated subsidy coefficient, the optimized subsidy coefficient is mainly controlled by the basic subsidy, followed by the targeted adjustment based on the minimum subsidy and the resource endowment and exploitation conditions of the block. This is consistent with the basis and original intention of the government in formulating fiscal policy, which is primarily based on the financial statements reported by enterprises to protect their internal revenue, and then adjust the subsidy according to its own expected benefit maximization.
Based on the analysis of the influencing factors of variable subsidy incentive coefficient in Equation (22), the changes in $\beta$ caused by changes in the uncertainty factors $q$, $a$, $n_1$, $n_2$, in the range of $\pm5\%$ and $\pm10\%$, respectively, are simulated. The results in Figure 7 demonstrate that when $a$ and $n_2$ are varied from -10\% to 10\%, the variation of $\beta$ changes in the scope of $-4.51\%$ to $4.09\%$. It does not affect remarkably on $\beta$ when $n_1$ is adjusted by $\pm5\%$ and $\pm10\%$. Compared to the other factors, $\beta$ is more sensitive to the social benefit coefficient ($q$), showing a relatively wide range of variation (6.99\%). This shows that the social benefit output coefficient has a very important role in the determination of the variable subsidy amount, which is consistent with the government’s purpose of implementing variable subsidies to incentivize enterprises based on the benefits generated by shale gas development projects. On the whole, the fluctuations of the model results caused by the changes of the above factors are maintained within $\pm7\%$, which indicates that the model has good robustness.

In addition, it is recommended to analyze the respective weights of environmental benefits, national tax revenue, employment growth, and national energy security benefits in the social benefits coefficient, which will further improve the accuracy of the model.

5. Conclusions

In this paper, first, the problems of the current indiscriminate subsidy are expressed and a new subsidy approach is proposed, which is a combination of a basic subsidy that guarantees a benchmark yield for companies and a variable subsidy that motivates companies to invest in shale gas development; then, the principal-agent relationship between the government and the firm is completely described. Based on these, the modeling of the differentiated subsidy model considering the resource endowment characteristics of shale gas blocks is put into practice. Theoretical results and case studies suggest that high-quality target blocks with good resource endowment and development conditions do not require additional incentive in the form of variable subsidies, and firms can be profitable with basic subsidies alone. In contrast, shale gas companies in resource-barren blocks with difficult development conditions still need variable subsidy incentives to promote aggressive investment, in addition to the required basic subsidies. This suggests that a differentiated subsidy approach is reasonably effective in the balanced and sustainable development of shale gas in China. The model sensitivity analysis results demonstrate that the range of model fluctuations caused by changes in uncertainty factors remains between -7\% and 7\%, indicating that the proposed model has good robustness in general. Therefore, the differential subsidy model proposed in this paper can be used as a reference for the quantitative design of subsidy optimization for shale gas development.

Moreover, the final cost of the proposed method is significantly reduced compared to the conventional one, in terms of financial expenditure by the government. Shale gas companies are also profitable, and their basic balance is guaranteed for development under any resource conditions. In this regard, using the proposed method of this article in energy policy can provide a decision basis for solving the cost-benefit dilemma, optimizing the subsidy effect, and enhancing the long-term development capacity for shale gas development.

6. Future Work

Based on what has been said, the following topic is suggested for further research on the model and method for measuring the amount of shale gas development subsidies established in this paper:

Complete and improve the differentiated subsidy model. The subsidy for shale gas development is influenced by a variety of factors, including technology, enterprise scale, and other factors in addition to the geological and economic factors studied in this paper, and further refinement of the model is needed to visualize their impact on the amount.

In addition, new methods, such as game theory and reinforcement learning, are used to coordinate and optimize the balance of interests among multiple agents and compare with the proposed principal-agent theory approach.

**Acronyms**

- $C_{all}$: Total cost of shale gas exploitation
- $R_{all}$: Revenue from shale gas exploitation
- $p$: Shale gas sales price
- $q$: Social benefit coefficient
- $s_0$: Basic subsidy
- $s_1$: Variable subsidy
- $S$: Subsidy amount
- $q_1$: Social benefit incentive coefficient
- $r_0$: Environmental benefit
- $r_1$: National tax revenue
- $r_2$: Employment growth
- $r_3$: National energy security
- $r_4$: Value-added tax
- $r_5$: Resource tax
- $r_6$: Urban construction tax
- $r_7$: Education tax surcharge
- $r_8$: Income tax
- $C_i$: Relative closeness
- $a$: Correlation coefficient between resource conditions and expected social benefits
- $C$: Cost of business operations
- $C_0$: Fixed cost
- $C_e$: Effort cost
- $C_r$: Risk cost
- $G$: Economic benefit
- $B$: Social benefit
- $c$: Enterprise’s effort cost coefficient
- $e$: Degree of effort of the enterprise
- $E(X)$: Government’s revenue function
- $E(Y)$: Enterprise’s revenue function
- $n_1$: The influence weight of social benefit coefficient on $\beta$
- $n_2$: The influence weight of resource endowment and exploitation conditions on $\beta$. 


Data Availability
The data used to support the findings of this study are included within the article.

Conflicts of Interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence that the work reported in this paper.

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