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Research article

Subsidizing farmers or service providers? Government intervention in agricultural outsourcing under yield uncertainty

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Abstract: Agricultural production outsourcing services can promote moderate-scale land management and improve agricultural production efficiency. This paper develops an agricultural supply chain game model under yield uncertainty and government budget constraints to examine farmers' production outsourcing decisions and compare two subsidy programs: the farmer subsidy program (FSP) and the service provider subsidy program (PSP). The results show that, without subsidies, farmers choose outsourcing only when yield uncertainty is sufficiently low and the service provider has a sufficiently strong production cost advantage. Under government subsidies, PSP generates higher farmers' profits and welfare than FSP when the subsidy budget is constrained, whereas these differences disappear when the budget is sufficiently large. The service provider earns a higher profit under FSP because the two programs affect service prices through different transmission mechanisms. Incorporating environmental external costs further shows that a higher environmental cost reduces the welfare-maximizing outsourcing acreage and optimal subsidy levels, and narrows the budget range over which PSP has a welfare advantage. Finally, PSP achieves higher subsidy-fund efficiency in improving farmers' profits and, under certain budget conditions, welfare.

Keywords: production outsourcing; yield uncertainty; government subsidy; budget constraint; agricultural supply chain
Mathematics Subject Classification: 58F15, 58F17, 53C35

1. Introduction

With the acceleration of agricultural modernization, integrating small farmers and modern agriculture is becoming increasingly important [1, 2]. However, this process still faces severe challenges, especially in developing countries. Constrained by multiple factors, such as resource endowments, land scale, and

financial status, small farmers usually face difficulties in adopting advanced machinery and technology, affecting food production's efficiency and productivity. Agricultural production outsourcing services offer a new way to realize the effective connection between small farmers and modern agriculture development. By purchasing outsourcing services, farmers can outsource some or all aspects of their agricultural production, such as tillage, planting, prevention, and harvesting, to service providers based on not changing the land contract management right, and agricultural harvest belongs to the farmers [3, 4].

Governments have implemented various subsidy policies to facilitate the development of agri-cultural outsourcing services [5]. Depending on the target of the subsidy, the subsidy policies can be divided into two types: one is that the government directly subsidizes farmers. Under the farmer subsidy program (FSP), the government provides subsidies to farmers for outsourcing acreage. Since 2013, the Ministry of Finance has allocated RMB 14.5 billion to subsidize farmers to receive social services per-mu basis; the other type is government subsidies to service providers. Under the service provider subsidy program (PSP), the government subsidizes the production inputs of service providers. In 2021, to cultivate and grow the mainstay of social services, the Chinese government carried out a pilot scheme of comprehensive subsidies to purchase agricultural machinery. It increased the subsidy proportion for weak links in agricultural production, and the subsidy for machinery and equipment needed for production activities in hilly areas reached 35 %.

Although outsourcing has become a new production mode and has been strongly supported by the government, whether farmers purchase outsourcing services is restricted by many factors, and the cost and benefits of outsourcing services should be fully weighed [6, 7]. In addition, the government can subsidize farmers or subsidize service providers. However, it remains unclear how the choice of subsidy recipient affects farmers' incomes, especially under budget constraints. Motivated by the above background, we aim to address the following questions:

(1) Are farmers willing to purchase production outsourcing services without subsidies?

(2) How do the government subsidy budget and yield uncertainty affect production, pricing, and profits in agricultural supply chains under the two service subsidy programs?

(3) How does the government budget constraint affect the relative performance of FSP and PSP, and under what conditions does the choice of subsidy recipient matter for economic efficiency?

To address these questions, we consider a supply chain consisting of multiple farmers, a farming material dealer, and a service provider, where farmers face yield uncertainty and the government offers outsourcing service subsidies. We first explore the boundary conditions for farmers to purchase production outsourcing services without subsidies, using independent production by farmers as a baseline model. Then, we comparatively analyze the impact of the two subsidy programs (FSP and PSP) on the supply chain's production, profits, and welfare.

The remainder of this paper is organized as follows. Section 2 reviews the related literature and highlights the paper's contributions. Section 3 presents the model setup. Section 4 examines farmers' production decisions without government subsidies. Section 5 develops the FSP and PSP models under budget constraints and derives the corresponding equilibrium outcomes. Section 6 analyzes the effects of yield uncertainty and subsidy budgets and compares the two subsidy programs. Section 7 concludes with managerial insights and future research directions

2. Literature review

This section reviews some literature on agricultural subsidy, production outsourcing, and agricultural supply chain management.

2.1. Agricultural subsidy

The influence of government subsidies on agricultural production and farmers' incomes has been widely discussed. Xie et al. [8] explore how government subsidies affect the success of three poverty alleviation programs. The results indicate that providing subsidies to poverty alleviation enterprises can improve the implementation of these programs. Jin et al. [9] construct an evolutionary game model to reflect the interaction relationships among farmers, third-party enterprises, and the government. They find that in regions characterized by a low concentration of farming, the government should give acquisition subsidies to farmers. Fan et al. [10] assess the impact of subsidies on agricultural yields and wealth distribution among farmers. Their research shows that excessive subsidies or overcompensation can increase income inequality, while a well-calibrated subsidy level contributes to a more equitable distribution of output and profits. These papers do not address the outsourced service of agricultural production. With the rise of social services, some studies have also analyzed agricultural production outsourcing subsidy policies. Xu et al. [11] explore how market-driven agricultural land transfer affects farmers' use of outsourced machinery services (OMS). Their findings indicate that subsidies for machinery purchases reduce the positive impact of market-oriented farmland transfer on OMS utilization. Zhang et al. [12] analyze the impact of outsourced fertilization and pesticide application (OF and OPA) on technical efficiency. The study suggests that subsidies should help farmers with different endowments make more rational decisions when purchasing OF and OPA. Our work differs from these studies in that we consider different production outsourcing subsidy policies and analyze the impact of these subsidies on various stakeholders.

2.2. Production outsourcing

Scholars mainly focus on outsourcing activities in the traditional manufacturing field. Hou et al. [13] analyze an OEM that delegates production tasks to two competing suppliers with differing production capacities. Niu et al. [14] consider an apparel supply chain consisting of two competing small retailers (Retailer 1 and Retailer 2), a strong sourcing agent, and a well-known fashion brand. The study finds that when demand uncertainty is high, Retailer 1's sourcing outsourcing strategy will shift from turnkey to consignment and then back to turnkey. Karamemis et al. [15] examine the outsourced decisions between the OEM and the contract manufacturer (CM). Their findings suggest that the profit of CM is limited to an amount the OEM is willing to share if the OEM sets the outsourced cost. However, these papers examine firms' production outsourcing activities based on demand uncertainty. What differentiates our model from the works mentioned above is that we model the yield uncertainty.

With the advance of agricultural modernization, people pay more attention to out- sourcing in agricultural production. Sun et al. [16] explore the factors influencing outsourcing of pest and disease management in rice production in China and its effects. Their findings indicate that farm size, the age of the household head, and other household characteristics are key drivers of outsourcing decisions. Deng et al. [17] analyze survey data from 4,864 farmer households in China to assess how outsourcing affects

agricultural productivity. The results show that farmers with lower-than-average productivity are more likely to outsource. Qian et al. [18] investigate how the ownership of farm machinery and the use of outsourced agricultural machinery services affect land leasing decisions among relatively large-scale farmers in China. However, none of these papers model the outsourcing of agricultural production.

2.3. Agricultural supply chain management

A growing literature focuses on agricultural supply chains under yield uncertainty. Cao et al. [19] consider a supply chain featuring a typical cooperative and a buyer and establish stylized game models with and without the blockchain-based platform. The result indicates that the involvement of the blockchain-based platform can lead to increased production quantity and total surplus of the supply chain. Yang et al. [20] analyzes fresh agricultural products supply chain vulnerability identification and evaluation. The result reveals that market supply-demand imbalance and human resources issues are the key vulnerability factors. Xu et al. [21] investigate the interaction between fresh produce firms' strategies to join platform blockchain technology and channel invasion decisions. The results show that the willingness to join blockchain platform technology will increase if the firms establish a third-party store.

Some studies have also introduced government subsidies into agricultural supply chains. He et al. [22] examines government regulations in a bioenergy supply chain involving power plants and farmers. Their findings suggest that if the proportion of farmers collecting bioenergy is high and government subsidies are lower than penalties, the subsidy policy should be chosen. Guo et al. [23] analyze the optimal government subsidy policy to promote GRMs, taking into account farmer heterogeneity. They conclude that the government should provide subsidies to both farmers and GRM firms when the effectiveness of GRMs is insufficient. Chintapalli and Tang [24] investigate a market composed of infinitesimally small, rational, and strategic farmers facing market and yield uncertainties. Their study shows that while both cost subsidies and MSP encourage increased production, cost subsidies result in higher crop yields compared to MSP. Existing agricultural supply chain studies mainly examine subsidy design without explicitly considering the outsourcing service market. As a result, they cannot capture how the choice of subsidy recipient affects subsidy transmission through service pricing, particularly when government spending is constrained.

2.4. Contributions and innovations

Compared to the existing related literature, the contributions and innovations of this study are summarized in the following three aspects: First, we incorporate farmers' production outsourcing decisions into an agricultural supply chain under yield uncertainty and characterize when farmers prefer outsourcing to independent production, thereby extending agricultural outsourcing research to endogenous outsourcing choices in a supply chain setting. Second, we compare two agricultural outsourcing subsidy programs: FSP and PSP, and reveal their different transmission mechanisms through service pricing. When the subsidy budget constraint is binding, an increase in the subsidy budget raises the service price under FSP but lowers it under PSP, leading to different production incentives and benefit distributions. Third, we identify fiscal scarcity as a boundary condition for the relative performance of the two subsidy programs. Within the welfare framework considered in this study, PSP generates higher farmers' profits and welfare than FSP when the subsidy budget is limited, whereas these differences disappear when the budget becomes sufficient. Moreover, PSP generates a

larger increase in farmers' profits per unit of government subsidy expenditure and, under certain budget conditions, a larger increase in welfare per unit of subsidy expenditure. These findings are conditional on the welfare metrics considered and should be interpreted within the scope of our model.

3. Notations and model setup

This section presents the framework for modeling two types of subsidy programs (i.e., FSP and PSP). We consider an agricultural supply chain including multiple farmers, an agricultural material dealer, and a specialized agricultural socialized service provider with supply-chain coordination capability. The farmers can produce themselves or outsource production to the service provider. In addition, to promote the development of agricultural outsourcing services, the government offers subsidies to the farmers or the service provider. Table 1 summarizes the main variables and parameters used in this paper.

Table 1. Notations.

Parameters	Definition
q_i	Acres planted by the farmer$i$;
p_s	Agricultural material prices;
λ_f	Subsidy amount per unit area;
λ_h	Input cost subsidy rate;
p_h	The service price decided by the service provider;
a, b	The market size and price sensitivity coefficient;
p_r	The retail price;
X	The yield per acre;
μ	Expected value of the per-acre yield X;
σ^2	Variance of the per-acre yield X;
c_f	Cost coefficients of production effort for farmers;
c_h	Cost coefficients of production effort for service providers;
β	Ratio of the coefficient of the cost of effort of the service provider and the farmer;
θ	Environmental external cost coefficient;
B	Government subsidy fund budget;
CS, SW	Consumer surplus and welfare;
π_{fi}, π_s, π_h	The profits of farmer i, agricultural material dealer and service provider.

Suppose there are n Cournot competing farmers in the market. Farmer i needs to decide the planting acreage q_i. Due to the vulnerability of agricultural production to uncontrollable factors, such as weather and soil, farm yields are uncertain [25–27]. Thus, it is assumed that the yield X per acre is a random variable. In addition, we further assume that the expected value and variance of X are $E(X) = \mu$ and $D(X) = \sigma^2$, respectively.

Following Agbo et al. [28] and Yi et al. [29], we assume that the cost function for farmer i under independent production is $C(q_i) = p_s q_i + c_f q_i^2$, where p_s denotes the agricultural material cost, such as pesticides, fertilizers, and seeds, required per acre and c_f is farmers' production effort cost coefficient, which is related to the production technology of the farmers, agricultural tools, and other factors. A larger c_f indicates lower independent production efficiency of farmers.

In addition, we use p_s to denote the agricultural material price, which is decided by the farming material dealer [30]. The cost of selling agricultural material is c_0.

When farmers outsource production to the service provider, farmers need to pay the cost of services p_h per unit area. Therefore, the total cost of farmer i under the production outsourcing is $(p_s + p_h)q_i$. In addition, we assume that the service provider's cost function is $c_h q_i^2$, where c_h is the effort cost coefficient of the service provider. Since service providers are more specialized in agricultural production, we assume that $c_h = \beta c_f$, where $0 < \beta < 1$. A smaller β indicates a lower production effort cost coefficient for the service provider and thus a greater production cost advantage.

To promote the development of agricultural outsourcing services, governments can adopt two subsidy policies: FSP and PSP. In FSP, the government subsidizes farmers who adopt production outsourcing services, with the total amount of subsidy being $\sum_{i=1}^{n} \lambda_f q_i$, where λ_f is the amount of subsidy per unit area. In PSP, the government subsidizes the input cost of the service provider, with the total amount of subsidy being $\sum_{i=1}^{n} \lambda_h c_h q_i^2$, where $\lambda_h \in (0, 1)$ is the proportion of subsidy.

In addition, we assume that the government is constrained by the upper limit of the financial budget B when implementing service subsidy policies. When the government implements service subsidy policies [31], it is constrained by the financial subsidy budget cap B. Therefore, subsidies to farmers or service providers cannot exceed the budget cap in this paper.

After cultivation, farmers sell the harvested agricultural products to consumers at the retail price p_r. Since an increase in aggregate market supply generally leads to a lower market-clearing price, we use a linear inverse demand function to capture the negative relationship between agricultural output and market price, which is commonly adopted in analytical studies of agricultural markets [10, 24]. Therefore, the retail price is given by$p_r = a - b\sum_{i=1}^{n} q_i X$, where a denotes the market size and b is the price sensitivity coefficient.

4. Without government subsidies

4.1. Farmers' independent production

When the farmer chooses to produce on his own, the profit functions of farmer i and the agricultural material dealer can be expressed as follows, respectively

$$\pi_{f_i}^{NO}(q_i) = E[(a - b\sum_{i=1}^{n} q_i X)q_i X - C(q_i)] = (a\mu - p_s)q_i - bq_i(\sum_{i=1}^{n} q_i)(\mu^2 + \sigma^2) - c_f q_i^2 \tag{1}$$

$$\pi_s^{NO}(p_s) = \sum_{i=1}^{n}(p_s - c_0)q_i = n(p_s - c_0)q_i \tag{2}$$

The game sequence between farmers and the agricultural material dealer is as follows: First, the agricultural material dealer decides the agricultural material price, and then the farmers decide the planting acreage. Using backward induction, we can obtain the following results.

Proposition 1. *If farmers choose to produce independently, the equilibrium results are as follows.*

(1) The planting acreage of farmer i and the agricultural material price are $q_i^{NO} = \frac{a\mu - c_0}{2[(n+1)b(\mu^2+\sigma^2)+2cf]}$, $p_s^{NO} = \frac{a\mu + c_0}{2}$. *(2) The profits of farmer i and the agricultural material dealer are* $\pi_{f_i}^{NO} = [b(\mu^2 + \sigma^2) + c_f](q_i^{NO})^2$, $\pi_s^{NO} = \frac{a\mu - c_0}{2} n q_i^{NO}$.

4.2. Farmers' production outsourcing

When farmers choose production outsourcing, the profit functions of farmer i, agricultural material dealer, and service provider are, respectively.

$$\pi_{fi}^{NS} = E[(a - b\sum_{i=1}^{n} q_i X)q_i X - p_s q_i - p_h q_i] = aq_i\mu - bq_i(\sum_{i=1}^{n} q_i)(\mu^2 + \sigma^2) - (p_s + p_h)q_i \tag{3}$$

$$\pi_s^{NS}(p_s) = \sum_{i=1}^{n}(p_s - c_0)q_i = n(p_s - c_0)q_i, \quad \pi_h^{NS} = \sum_{i=1}^{n}(p_h q_i - c_h q_i^2) = n(p_h q_i - \beta c_f q_i^2) \tag{4}$$

The service provider in this paper represents a specialized agricultural socialized service organization with supply-chain coordination capability. In practice, leading agricultural service organizations may integrate agricultural inputs, production services, and farmers [32]. For example, Suhe Agricultural Socialized Service Co., Ltd. in Jiangsu Province integrates upstream agricultural input supply, production services, and downstream grain marketing. Moreover, agricultural outsourcing service providers may adjust service prices according to market conditions [33]. Based on these practices, we consider a service-provider-led agricultural supply chain, where the service provider first determines the service price, followed by the agricultural material dealer determining the agricultural material price, and farmers finally determining their planting acreage. This sequence reflects the decision hierarchy of a service-provider-led supply chain rather than a strict chronological ordering of transactions. Using backward induction, we obtain the following results.

Proposition 2. *If farmer i chooses to outsource production and there is no subsidy, the equilibrium results are as follows.*

(1) The planting acreage of farmer i, the agricultural material price, and the service price are $q_i^{NS} = \frac{a\mu - c_0}{2[2(n+1)b(\mu^2+\sigma^2)+\beta c_f]}$, $p_s^{NS} = \frac{(a\mu - c_0)(n+1)b(\mu^2+\sigma^2)}{2[2(n+1)b(\mu^2+\sigma^2)+\beta c_f]}$, $p_h^{NS} = c_0 + \frac{(a\mu - c_0)[b(n+1)(\mu^2+\sigma^2)+\beta c_f]}{2(n+1)b(\mu^2+\sigma^2)+\beta c_f}$.

(2) The profits of farmer i, the agricultural material dealer, and the service provider are $\pi_{fi}^{NS} = [b(\mu^2 + \sigma^2)](q_i^{NS})^2, \pi_s^{NS} = nb(n+1)(\mu^2 + \sigma^2)(q_i^{NS})^2, \pi_h^{NS} = n[2b(n+1)(\mu^2 + \sigma^2) + \beta c_f](q_i^{NS})^2$.

5. With government subsidies

5.1. FSP

Under FSP, the government provides subsidies to farmers based on the service acreage. Thus, the profit functions of farmer i, agricultural material dealer, and service provider are, respectively.

$$\pi_{f_i}^{OF}(q_i) = E[(a - b\sum_{i=1}^{n} q_i X)q_i X - (p_s + p_h - \lambda_f)q_i] = [a\mu - bnq_i(\mu^2 + \sigma^2) - p_s - p_h + \lambda_f]q_i \tag{5}$$

$$\pi_s^{OF}(p_s) = \sum_{i=1}^{n}(p_s - c_0)q_i = n(p_s - c_0)q_i, \quad \pi_h^{OF}(p_h) = \sum_{i=1}^{n}(p_h q_i - c_h q_i^2) = n(p_h q_i - \beta c_f q_i^2) \tag{6}$$

Following existing analytical studies on agricultural supply chains and government intervention [10, 31], we evaluate measured supply-chain economic welfare (hereafter, welfare) by considering both the economic surplus generated within the agricultural supply chain and the environmental external costs associated with

agricultural production. Specifically, welfare consists of consumer surplus and the profits of farmers, the agricultural material dealer, and the service provider, net of government subsidy expenditure and environmental external costs. Therefore, under FSP, the welfare function is given by

$$\begin{aligned} SW^{OF}(q_i) &= \sum_{i=1}^{n} \pi_f^{OF} + \pi_s^{OF} + \pi_h^{OF} + CS^{OF} - \sum_{i=1}^{n} \lambda_f q_i^{OF} - \sum_{i=1}^{n} \theta q_i^{OF} \\ &= n(a\mu - c_0 - \theta) q_i^{OF} - n[\beta c_f + \frac{1}{2} b(\mu^2 + \sigma^2) n](q_i^{OF})^2 \end{aligned} \tag{7}$$

where θ denotes the environmental external cost per unit of outsourced acreage.

5.2. PSP

Under PSP, the government covers part of the input cost for the service provider. Therefore, the profit functions of farmer i, agricultural material dealer, and service provider are, respectively.

$$\pi_{f_i}^{OH}(q_i) = E[(a - b\sum_{i=1}^{n} q_i X) q_i X - p_s q_i - p_h q_i] = a q_i \mu - b q_i (\sum_{i=1}^{n} q_i)(\mu^2 + \sigma^2) - (p_s + p_h) q_i \tag{8}$$

$$\pi_s^{OH}(p_s) = \sum_{i=1}^{n} (p_s - c_0) q_i = n(p_s - c_0) q_i, \pi_h^{OH} = \sum_{i=1}^{n} [p_h q_i - (1 - \lambda_h) \beta c_f q_i^2] \tag{9}$$

Similar to the case of FSP, the welfare function under PSP is given by

$$SW^{OH}(q_i) = n(a\mu - c_0 - \theta) q_i^{OH} - n[\beta c_f + \frac{1}{2} b(\mu^2 + \sigma^2) n](q_i^{OH})^2 \tag{10}$$

Table 2. Equilibrium values of agricultural supply chain under FSP.

Quantity	$B < B_f$	$B \geq B_f$
q_i^{OF}	$\frac{F + \eta}{4D}$	$\frac{F - \theta}{2\beta c_f + b(\mu^2 + \sigma^2) n}$
p_s^{OF}	$c_0 + \frac{(F + \eta) b(n + 1)(\mu^2 + \sigma^2)}{4D}$	$c_0 + \frac{b(F - \theta)(n + 1)(\mu^2 + \sigma^2)}{2\beta c_f + b(\mu^2 + \sigma^2) n}$
p_h^{OF}	$\frac{(F + \eta)[b(n + 1)(\mu^2 + \sigma^2) + \beta c_f]}{2D}$	$\frac{2(F - \theta)[b(n + 1)(\mu^2 + \sigma^2) + \beta c_f]}{2\beta c_f + b(\mu^2 + \sigma^2) n}$
λ_f^{OF}	$\frac{\eta - F}{2}$	$\frac{bF(3n + 4)(\mu^2 + \sigma^2) - 2\theta D}{2\beta c_f + b(\mu^2 + \sigma^2) n}$
π_{fi}^{OF}	$\frac{(F + \eta)^2 b(\mu^2 + \sigma^2)}{16D^2}$	$\frac{(F - \theta)^2 b(\mu^2 + \sigma^2)}{[2\beta c_f + b(\mu^2 + \sigma^2) n]^2}$
π_s^{OF}	$\frac{(F + \eta)^2 n b(n + 1)(\mu^2 + \sigma^2)}{16D^2}$	$\frac{(F - \theta)^2 b n(n + 1)(\mu^2 + \sigma^2)}{[bn(\mu^2 + \sigma^2) + 2\beta c_f]^2}$
π_h^{OF}	$\frac{(F + \eta)^2 n}{16D}$	$\frac{n(F - \theta)^2 [2b(n + 1)(\mu^2 + \sigma^2) + \beta c_f]}{[bn(\mu^2 + \sigma^2) + 2\beta c_f]^2}$
SW^{OF}	$\frac{[(7n + 8) b(\mu^2 + \sigma^2) + 2\beta c_f] n(F + \eta)^2}{32D^2} - B - \frac{n\theta(F + \eta)}{4D}$	$\frac{n(F - \theta)^2}{2[2\beta c_f + b(\mu^2 + \sigma^2) n]}$

5.3. Equilibrium solutions for agricultural supply chains under two subsidy programs

The government acts as the Stackelberg leader and determines the subsidy level to maximize welfare subject to the subsidy budget constraint. Under FSP, the government chooses the per-unit-area subsidy λ_f, subject to $\sum_{i=1}^{n} \lambda_f q_i \leq B$. Under PSP, the government chooses the input cost subsidy rate λ_h, subject to $\sum_{i=1}^{n} \lambda_h c_h q_i^2 \leq B$. After the government announces the subsidy level, the service provider determines the service price p_h, followed by the agricultural material dealer determining the agricultural material price p_s. Finally, farmers determine their planting acreage q_i. The game is solved by backward induction.

Table 3. Equilibrium solutions of agricultural supply chain under PSP.

Quantity	$B < B_h$	$B \geq B_h$
q_i^{OH}	$\frac{nF+Y}{4nD}$	$\frac{F-\theta}{2\beta c_f + b(\mu^2+\sigma^2)n}$
p_s^{OH}	$c_0 + \frac{(nF+Y)b(n+1)(\mu^2+\sigma^2)}{4nD}$	$c_0 + \frac{b(F-\theta)(n+1)(\mu^2+\sigma^2)}{2\beta c_f + b(\mu^2+\sigma^2)n}$
p_h^{OH}	$F - \frac{(nF+Y)b(n+1)(\mu^2+\sigma^2)}{2nD}$	$F - \frac{2(F-\theta)b(n+1)(\mu^2+\sigma^2)}{2\beta c_f + b(\mu^2+\sigma^2)n}$
λ_h^{OH}	$1 - \frac{F(Y-nF) - 16Bb(n+1)(\mu^2+\sigma^2)}{8B\beta c_f}$	$\frac{Fb(3n+4)(\mu^2+\sigma^2) - 2\theta D}{2\beta c_f(F-\theta)}$
π_{fi}^{OH}	$\frac{(nF+Y)^2 b(\mu^2+\sigma^2)}{16n^2D^2}$	$\frac{(F-\theta)^2 b(\mu^2+\sigma^2)}{[2\beta c_f + b(\mu^2+\sigma^2)n]^2}$
π_s^{OH}	$\frac{(nF+Y)^2 nb(n+1)(\mu^2+\sigma^2)}{16n^2[2b(n+1)(\mu^2+\sigma^2)+\beta c_f]^2}$	$\frac{(F-\theta)^2 bn(n+1)(\mu^2+\sigma^2)}{[bn(\mu^2+\sigma^2)+2\beta c_f]^2}$
π_h^{OH}	$\frac{F(nF+Y)}{8[2b(n+1)(\mu^2+\sigma^2)+\beta c_f]}$	$\frac{nF(F-\theta)}{2[bn(\mu^2+\sigma^2)+2\beta c_f]}$
SW^{OH}	$\frac{8bnB^2(4+3n)(\mu^2+\sigma^2)}{(Y-nF)^2} + \frac{2BnF}{Y-nF} - B - \frac{\theta(nF+Y)}{4D}$	$\frac{n(F-\theta)^2}{2[bn(\mu^2+\sigma^2)+2\beta c_f]}$

Proposition 3. *When farmer i chooses to outsource production, the equilibrium decisions, profits, and the welfare of supply chains under two subsidy policies are presented in Tables 2 and 3.*

Where $B_f = \frac{n(F-\theta)[Fb(3n+4)(\mu^2+\sigma^2)-2\theta D]}{[2\beta c_f+b(\mu^2+\sigma^2)n]^2}$, $\eta = \sqrt{F^2 + \frac{8BD}{n}}$, $F = a\mu - c_0$,$Y = \sqrt{n^2F^2 + 16BnD}$, $B_h = \frac{n(F-\theta)[bF(3n+4)(\mu^2+\sigma^2)-2\theta D]}{2[2\beta c_f+b(\mu^2+\sigma^2)n]^2}$, $D = 2b(n+1)(\mu^2+\sigma^2) + \beta c_f$.

6. Discussion of model results

This section first analyzes the production outsourcing strategies of farmers without subsidies and then studies how yield uncertainty and budget constraints affect the equilibrium solution of agricultural supply chains under the two subsidy programs. Finally, this study discusses the government's optimal subsidy policy and capital expenditure efficiency by comparing the agricultural supply chain's decisions, profits, and welfare under the FSP and PSP policies.

For illustrative purposes, some numerical examples are also presented in this section. This study considers a three-level agricultural supply chain that consists of multiple farmers, a farming material dealer, and a service provider, where farmers face some yield uncertainty and grow rice. Further, it is assumed that the yield X of agricultural products per unit area is uniformly distributed $U[\mu-\alpha, \mu+\alpha]$,

so its variance is $\sigma^2 = \frac{\alpha^2}{3}$. In addition, referring to data from the World Food and Agriculture Statistical Yearbook 2020 , we assign the following values to the parameters of the agricultural supply chain: $a = 3500$ (CNY/t), $b = 0.5$, $c_0 = 500$ (CNY/mu), $\mu = 0.5$ (t/mu), $c_f = 100$, $\alpha = 0.3$, $n = 10$,$c_h = 50$. In this case, we have $\sigma^2 = 0.03, \beta = 0.5$.

6.1. Farmers' production outsourcing strategies

By comparing the planting acreage and farmers' profits in Lemma 1 and Lemma 2, we can get the following Proposition.

Proposition 4. *(1) If* $\sigma^2 < \sigma_1^2$, *then* $q_i^{NS} > q_i^{NO}$; *(2) If* $\sigma^2 \geq \sigma_1^2$, *then* $q_i^{NS} \leq q_i^{NO}$; *(3)* $\pi_{fi}^{NS} > \pi_{fi}^{NO}$, *if* $\sigma^2 \geq \sigma_2^2$ *and* $\beta < \beta_1$; *otherwise, when* $\sigma^2 \geq \sigma_2^2$ *or* $\sigma^2 < \sigma_2^2$ *and* $\beta \geq \beta_1$, $\pi_{fi}^{NS} \leq \pi_{fi}^{NO}$, *where* $\beta_1 = \sqrt{\frac{t[t(n+1)+2c_f]^2-3(t+c_f)(n+1)^2t^2}{(t+c_f)c_f^2}} - \frac{(n+1)t}{c_f}, \sigma_2^2 = \sqrt{\frac{[(3n-1)^2+32]c_f^2}{16b^2(n+1)^2}} - \frac{(3n-1)c_f}{4b(n+1)} - \mu^2, \sigma_1^2 = \frac{(2-\beta)c_f}{b(n+1)} - \mu^2, \quad t = b(\mu^2+\sigma^2).$

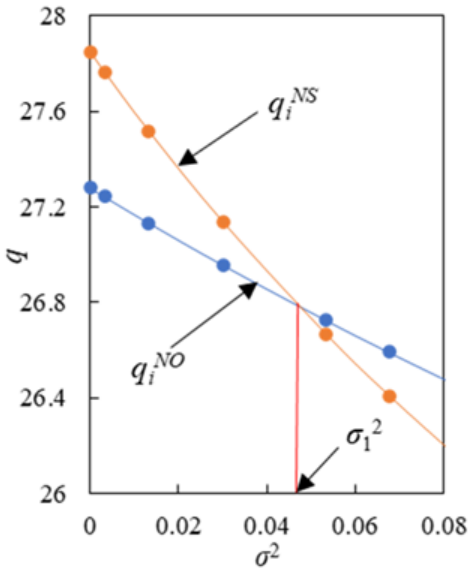


Figure 1. q_i under two production paths.

Proposition 4 (1) and Figure 1 show that in the absence of subsidies when the yield uncertainty of agricultural products is small, farmers plant more acres under production outsourcing than under independent production. However, farmers' planting willingness under independent production is higher when the yield uncertainty risk is large. This suggests that when the yield uncertainty risk of agricultural products is high, farmers are less motivated to outsource their land to service providers, which may hinder the scaling-up of outsourcing services. The management insight is that the government can reduce the risk of outsourcing agricultural production by promoting agricultural insurance, strengthening agricultural infrastructure construction, and guiding farmers to adjust their production structure to promote the scaling up of land services.

Proposition 4 (3) shows that farmers obtain a higher profit under production outsourcing only when the yield uncertainty of agricultural products is small and the service provider's production cost advantage is large. Otherwise, farmers always prefer to produce on their own. The yellow shaded areas

in Figure 2 represent areas where farmers' profits are greater under outsourcing than under independent production. The management insight is that to promote the development of the agricultural production outsourcing service, the government should not only guide farmers to purchase agricultural insurance but also consider establishing special funds to strengthen the investment in production equipment renewal and technological improvement of service providers. For example, in 2021, Huantai County in Shandong Province, based on fully implementing policies, such as subsidies for the purchase of agricultural machinery, will give certain subsidies to the purchase of deep-opening fertilizer preparation machinery, self-propelled four-wheeled high-pole operation spraying machinery, and new wide-width wheat precision sowing machinery, guiding agricultural social service organizations to update machinery and equipment and improve service capabilities.

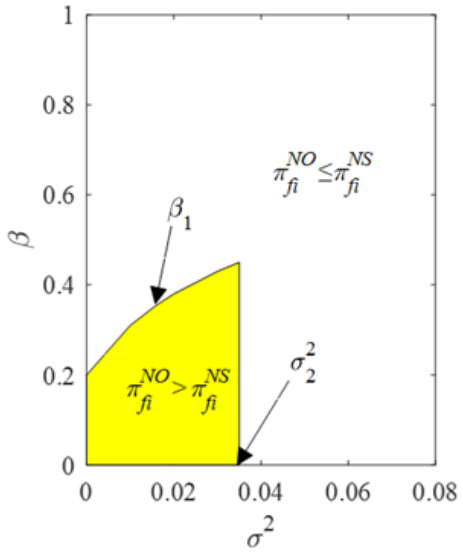


Figure 2. π_{fi} under two production paths.

6.2. Impact of yield uncertainty

The impact of yield fluctuation risk on the equilibrium outcomes of supply chains under two outsourcing subsidy policies can be easily obtained from Tables 2 and 3, and the results are shown below:

Proposition 5. *(1)* $\frac{dq_i^{OF}}{d\sigma^2} < 0, \frac{dp_s^{OF}}{d\sigma^2} > 0, \frac{d\lambda_f^{OF}}{d\sigma^2} > 0$; *(2) If* $B \geq B_f$, $\frac{dp_h^{OF}}{d\sigma^2} > 0$; *(3)* $\frac{dq_i^{OH}}{d\sigma^2} < 0, \frac{dp_s^{OH}}{d\sigma^2} > 0, \frac{dp_h^{OH}}{d\sigma^2} < 0, \frac{d\lambda_h^{OH}}{d\sigma^2} > 0$

Proposition 5 shows that under the two outsourcing subsidy programs, the acreage planted by farmers decreases with the yield fluctuation risk of agricultural products. Therefore, greater yield uncertainty induces the government to increase the subsidy intensity. When the budget constraint is binding, however, total subsidy expenditure remains capped at B. Moreover, the agricultural material dealer benefits from it by increasing the agricultural material price. The management implication is that the government can reduce the negative impact of yield uncertainty by promoting agricultural insurance and regulating the agricultural material price market while implementing the agricultural production outsourcing subsidy policy, to promote the appropriate scale of agricultural management.

Proposition 5 suggests that under FSP, when the subsidy budget is relatively sufficient, the service provider will raise the service price. The management insight is that, when farmers are the subsidy recipients and the subsidy budget is relatively sufficient, tighter control of subsidy expenditure can help limit farmers' service costs. For example, in 2023, Liaoning Province, focusing on grain and soybean oilseed production, supported small farmers in entrusting key aspects, such as plowing, planting, preventing, and harvesting, to service organizations through financial subsidies per mu, and stipulated that the total amount of subsidies for each aspect of a single season's crop per mu should not exceed 65 CNY.

In addition, under PSP, the service price always decreases as the yield fluctuation risks increase. This is because yield uncertainty increases the production loss risk for agricultural products, lowering farmers' willingness to outsource production. At this point, the service provider needs to stimulate farmers' potential service demand by lowering the service price and encouraging farmers to expand the area under outsourced cultivation.

Proposition 6. *(1)* $\frac{d\pi_{fi}^{OF}}{d\sigma^2} > 0, \frac{d\pi_s^{OF}}{d\sigma^2} > 0$; *(2) If* $B < B_f$, $\frac{d\pi_h^{OF}}{d\sigma^2} < 0$; *(3) If* $B \geq B_f$, $\frac{d\pi_h^{OF}}{d\sigma^2} \geq 0, \frac{dSW^{OF}}{d\sigma^2} \leq 0$; *(4)* $\frac{d\pi_{fi}^{OH}}{d\sigma^2} > 0, \frac{d\pi_s^{OH}}{d\sigma^2} > 0, \frac{d\pi_h^{OH}}{d\sigma^2} < 0$; *(5) If* $B \geq B_h$, $\frac{dSW^{OH}}{d\sigma^2} < 0$.

Proposition 6 shows that as the yield uncertainty risk increases, the profits of both farmers and the agricultural material dealer increase under the two subsidy programs. Figures 3 and 4 further illustrate that welfare decreases as yield uncertainty increases. This may be because when the yield uncertainty risk becomes high, the government provides more subsidies (see Proposition 5) even though the agricultural material dealers profit from setting higher agricultural material prices, which can offset the negative impact of higher agricultural material prices. This also suggests that when farmers outsource high-risk agricultural products to service providers, farmers can earn more profit from the subsidy programs. The management insight is that if the government implements an outsourcing subsidy policy, farmers have an incentive to deliberately grow high-risk agricultural products, regardless of whether the subsidy is targeted at farmers or service providers. Thus, the government can focus subsidies on agricultural products with lower production risks when formulating agricultural outsourcing subsidy policies.

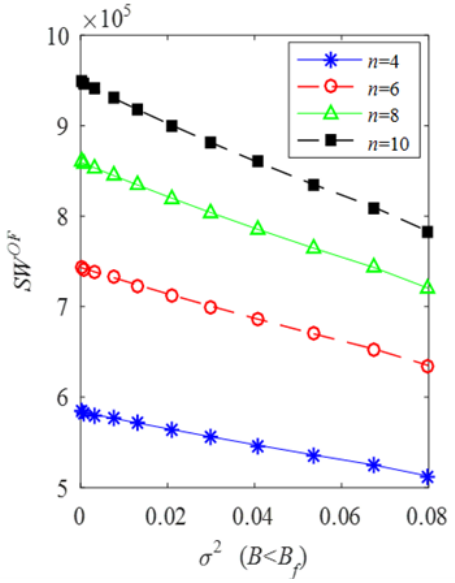


Figure 3. Impact of σ^2 on SW under FSP.

Proposition 6 reveals that under FSP, the impact of the yield fluctuation risk on the service provider's profits depends on the government's subsidy fund budget. If the subsidy fund budget is relatively insufficient, the service provider's profits decrease as the yield fluctuation risk increases. However, when the fund budget is relatively sufficient, the service provider's profits increase with the yield uncertainty risk. Under PSP, the service provider's profits decrease with the yield fluctuation risk. This may be because, in a situation where the government subsidizes farmers and has an adequate subsidy budget, although farmers' outsourced acreage decreases as the risk of yield uncertainty increases, the service provider offsets the adverse impact of the decline in outsourcing area by charging higher service fees, so the service provider's profits increase. Under PSP, however, as the yield uncertainty risk of agricultural products increases, both the outsourced area and the service price decrease, leading to lower profits for the service provider. The management insight is that when the government's outsourcing subsidy target is farmers and the subsidy budget is insufficient, or when the subsidy target is the service provider, the government can encourage the service provider to reduce the adverse impact of yield uncertainty on itself by purchasing agricultural insurance; and when the government's subsidy target is farmers and the subsidy budget is sufficient, the government needs to increase the support of the service providers to offer operational services for the farmers who grow high-risk agricultural products, which may support the development of service providers.

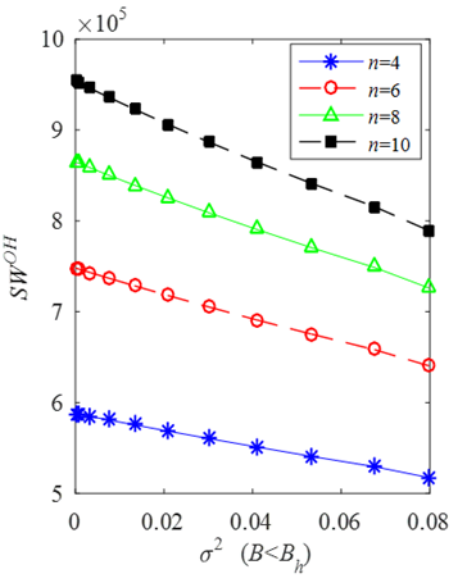


Figure 4. Impact of σ^2 on SW under PSP.

6.3. Impact of government subsidy budget

When the government subsidy budget is insufficient, (i. e., $B < B_f$or $B < B_h$), the impacts of the government subsidy budget on the equilibrium outcomes of the agricultural supply chain are shown in the following proposition.

Proposition 7. *(1)* $\frac{dq_i^{OF}}{dB} > 0, \frac{dp_s^{OF}}{dB} > 0, \frac{dp_h^{OF}}{dB} > 0, \frac{d\lambda_f^{OF}}{dB} > 0$; *(2)* $\frac{dq_i^{OH}}{dB} > 0, \frac{dp_s^{OH}}{dB} > 0, \frac{dp_h^{OH}}{dB} < 0, \frac{d\lambda_h^{OH}}{dB} > 0$; *(3)* $\frac{d\pi_{fi}^{OF}}{dB} > 0, \frac{d\pi_s^{OF}}{dB} > 0, \frac{d\pi_h^{OF}}{dB} > 0$; *(4)* $\frac{d\pi_{fi}^{OH}}{dB} > 0, \frac{d\pi_s^{OH}}{dB} > 0, \frac{d\pi_h^{OH}}{dB} > 0$.

Proposition 7 shows that under both subsidy programs, the outsourcing area increases with the government subsidy budget. In addition, under FSP, the service price increases with the subsidy budget. However, under PSP, the service price decreases with the subsidy budget. The management insight is that while the government implements the agricultural outsourcing subsidy policy to encourage farmers to expand the outsourcing area, it also needs to set up a price monitoring mechanism to detect excessive service prices and agricultural material prices promptly and take measures to protect the interests of farmers.

In addition, Proposition 7 reveals that as the subsidy budget increases, the profits of farmers, agricultural material dealers, and service providers increase. This implies that an increase in the subsidy budget raises the profits of all supply-chain members within the parameter region considered, thus achieving Pareto improvement of supply chain systems. The management insight is that the government can use subsidies to encourage cooperation among farmers, agricultural material dealers, and service providers to promote resource sharing and mutual benefit.

6.4. Comparative analysis of government subsidy strategies

This section first compares and analyzes the acreage, farm price, service price, profits, and welfare of the agricultural supply chain under different subsidy programs and then explores the two subsidy programs in terms of capital subsidy efficiency.

6.4.1. Planting acreage and prices

Proposition 8. *(1) If* $B < B_f$*, then* $q_i^{OH} > q_i^{OF}$*,* $p_s^{OH} > p_s^{OF}$*; (2) If* $B \geq B_f$*, then* $q_i^{OH} = q_i^{OF}$*,* $p_s^{OH} = p_s^{OF}$*; (3) For any B, there exists* $p_h^{OH} < p_h^{OF}$*.*

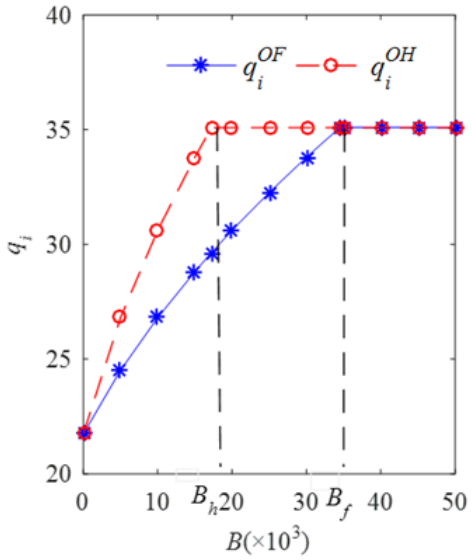


Figure 5. Farmers' acreage under different subsidies.

Proposition 8 (1) and Figure 5 show that when the government subsidy budget is constrained, PSP induces a larger planting acreage than FSP, but is also associated with a higher agricultural material price. This is because PSP reduces the service provider's effective production cost, thereby stimulating farmers' outsourcing demand and expanding planting acreage. The resulting increase in demand for

agricultural materials enables the agricultural material dealer to charge a higher price. In contrast, under FSP, part of the subsidy is transmitted through the service price, leading to a smaller expansion in planting acreage and a lower agricultural material price. Proposition 8 (2) further shows that when the subsidy budget is sufficiently large, the differences in planting acreage and agricultural material price between the two subsidy programs disappear.

Proposition 8 (3) and Figure 6 further show that the equilibrium service price is lower under PSP than under FSP for any positive subsidy budget. The two subsidy programs operate through different transmission channels: FSP directly increases farmers' effective purchasing power for outsourcing services and allows the service provider to capture part of the subsidy through a higher service price, whereas PSP reduces the service provider's effective production cost and induces it to lower the service price to expand outsourcing demand. Therefore, when reducing farmers' service payments is an explicit policy objective, subsidizing the service provider may result in a lower equilibrium service price, although the overall policy evaluation should also consider fiscal expenditure and welfare effects.

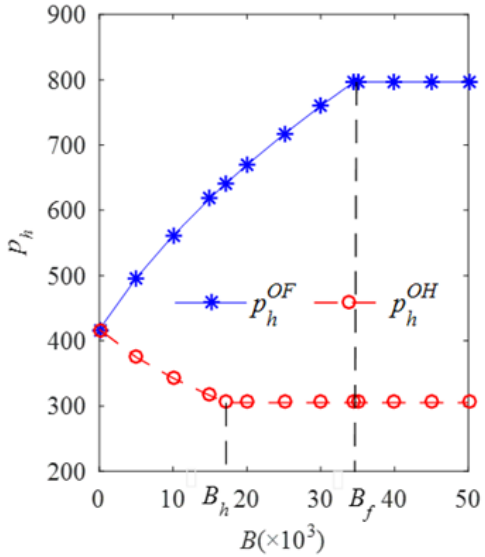


Figure 6. Service price under different subsidies.

6.4.2. Profits and welfare

Proposition 9. *(1) If $B < B_f$, then $\pi_{fi}^{OH} > \pi_{fi}^{OF}$, $\pi_s^{OH} > \pi_s^{OF}$, $SW^{OH} > SW^{OF}$; (2) For any B, there exists $\pi_h^{OF} > \pi_h^{OH}$; (3) If $B \geq B_f$, then $\pi_{fi}^{OF} = \pi_{fi}^{OH}$, $\pi_s^{OH} = \pi_s^{OF}$, $SW^{OF} = SW^{OH}$.*

Proposition 9, Figures 7 and 8 show that when the government subsidy budget is constrained, farmers obtain higher profits and welfare is higher under PSP than under FSP. When the subsidy budget is sufficiently large, however, the differences in farmers' profits and welfare between the two subsidy programs disappear. This result is closely related to the different subsidy-transmission mechanisms identified in Proposition 8. Under a limited budget, PSP induces a larger outsourcing acreage than FSP, thereby generating greater production and consumption surplus. As the subsidy budget increases, both programs eventually reach the welfare-maximizing outsourcing scale, at which point their effects on farmers' profits and welfare converge. In practice, agricultural service subsidies in China may be

allocated either to service providers or directly to farmers, with the ultimate objective of benefiting small farmers [34]. Therefore, when the subsidy budget is limited and the policy objective emphasizes farmers' income and welfare, the choice of subsidy recipient becomes particularly important.

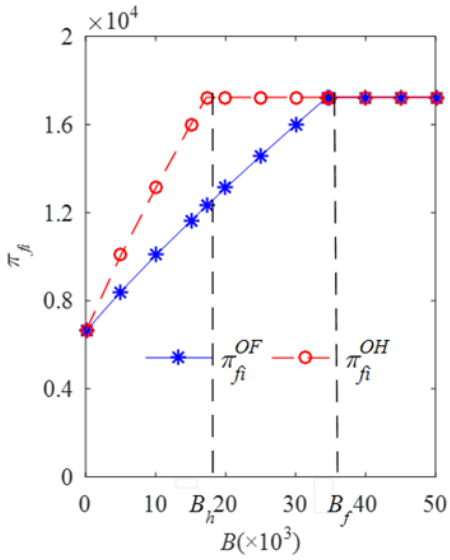


Figure 7. Farmers' profits under different subsidies.

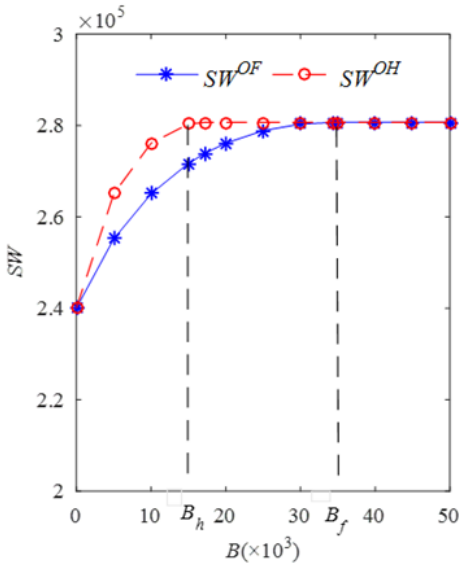


Figure 8. Welfare under different subsidies.

Proposition 9 (2) further shows that the service provider earns a higher profit under FSP than under PSP for any positive subsidy budget within the parameter region considered. This difference arises from the distinct service-price responses under the two subsidy programs. Under FSP, the subsidy increases farmers' effective purchasing power for outsourcing services, allowing the service provider to capture part of the subsidy through a higher service price. Under PSP, by contrast, the subsidy directly reduces the service provider's effective production cost, and the provider lowers the service price to

expand farmers' outsourcing demand. Consequently, the service provider captures a larger share of the subsidy-induced benefit under FSP. This result suggests that when subsidies are provided directly to farmers, price monitoring may be necessary to limit excessive subsidy capture through higher service charges. For example, in Xingcheng City, Liaoning Province, the government used the lowest quoted service fee of 110 yuan per mu as the benchmark price for the 2022 agricultural production hosting program and disclosed it publicly.

Corollary 1. *An increase in the environmental external cost reduces the welfare-maximizing outsourcing acreage and the optimal subsidy levels under both FSP and PSP. Moreover,* $\frac{\partial B_f}{\partial \theta} < 0, \frac{\partial B_h}{\partial \theta} < 0$. *Therefore, a larger environmental external cost narrows the budget range over which PSP generates higher welfare than FSP. For a given subsidy budget, this welfare advantage may disappear when the environmental external cost is sufficiently large.*

This result indicates that incorporating environmental external costs does not overturn the relative welfare ranking between the two subsidy programs, but narrows the parameter region in which PSP has a welfare advantage. This is because the environmental cost is common to outsourced production under both subsidy programs and therefore affects the welfare-maximizing outsourcing scale rather than directly favoring either subsidy recipient.

6.4.3. Subsidy efficiency analysis

The main purpose of the government's outsourcing subsidy policy is to benefit farmers and generate more welfare. Therefore, when analyzing the subsidy fund efficiency of FSP and PSP, the indicator used is the efficiency of subsidies associated with increases in farmers' profits and welfare, that is, the efficiency of unit government subsidy expenditure to increase farmers' profits and welfare. Let the value added to farmers' profits and welfare under different government subsidies be $\Delta(\pi_{fi}^{j}) = \pi_{fi}^{j} - \pi_{fi}^{NS}$, $\Delta(SW^{j}) = SW^{j} - SW^{NS}$, where $j = OF, OH$. In addition, we use GS to denote the government subsidy expenditure. Therefore, the government subsidy expenditure under FSP is $GS^{OF} = \sum_{i=1}^{n} \lambda_f^{OF} q_i^{OF}$, and government subsidy expenditure under PSP is $GS^{OH} = \sum_{i=1}^{n} \lambda_h^{OH} c_h (q_i^{OH})^2$. By comparing the efficiency of the two subsidy programs in improving farmers' profits and welfare, the following results can be obtained:

Proposition 10. *(1)*$\frac{\Delta(\pi_{fi}^{OF})}{GS^{OF}} < \frac{\Delta(\pi_{fi}^{OH})}{GS^{OH}}$; *(2)If*$B \geq B_h$, $\frac{\Delta(SW^{OF})}{GS^{OF}} < \frac{\Delta(SW^{OH})}{GS^{OH}}$.

Proposition 10, Figures 9 and 10 show that PSP generates a larger increase in farmers' profits per unit of government subsidy expenditure than FSP. In addition, when $B \geq B_h$, PSP also generates a larger increase in welfare per unit of subsidy expenditure. Although the two subsidy programs may eventually achieve the same levels of farmers' profits and welfare when the subsidy budget is sufficiently large (see Proposition 9 (3)), FSP requires greater government expenditure to achieve the same outcome. This difference arises because PSP directly reduces the service provider's effective production cost and lowers the equilibrium service price, thereby stimulating farmers' outsourcing demand with relatively less fiscal expenditure. By contrast, under FSP, part of the subsidy is transmitted into a higher service price, which weakens the fiscal leverage of the subsidy. Therefore, within the welfare framework considered in this study, PSP exhibits a higher subsidy-fund efficiency in improving farmers' profits, and, when $B \geq B_h$, also in improving welfare. In practice, agricultural support programs in China also provide direct support to qualified service providers through measures such as agricultural machinery

subsidies, comprehensive mechanization demonstration programs, and unified crop pest and disease control subsidies.

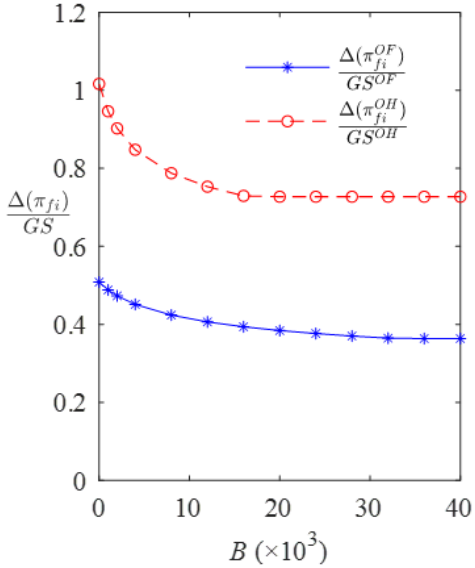


Figure 9. Farmers' profits increase efficiency.

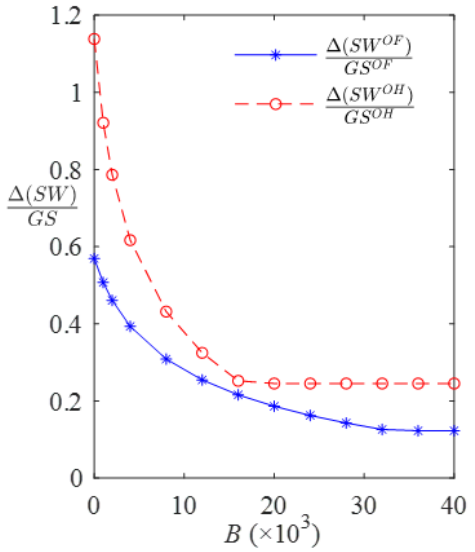


Figure 10. Welfare improves efficiency.

7. Conclusions

7.1. Main conclusions

This paper considers an agricultural supply chain with multiple farmers, an agricultural material dealer, and a service provider, where farmers face yield uncertainty. We develop a game model to examine farmers'

production outsourcing decisions and compare two outsourcing subsidy programs, namely FSP and PSP, under government budget constraints. The results show that, without government subsidies, farmers prefer production outsourcing only when yield uncertainty is sufficiently low and the service provider has a sufficiently strong production cost advantage; otherwise, independent production is preferred. Under the subsidy programs, greater yield uncertainty can increase farmers' profits within the parameter region considered, while the service provider earns a higher profit under FSP than under PSP.

Further analysis shows that the relative performance of FSP and PSP depends critically on the government subsidy budget. When the budget is constrained, PSP induces a larger outsourcing acreage and generates higher farmers' profits and welfare than FSP. When the budget is sufficiently large, the differences in outsourcing acreage, farmers' profits, and welfare between the two programs disappear. The two subsidy programs also operate through distinct transmission channels: FSP primarily increases farmers' effective purchasing power for outsourcing services and is associated with a higher service price, whereas PSP directly reduces the service provider's effective production cost and lowers the service price.

Incorporating environmental external costs further shows that a larger environmental cost reduces the welfare-maximizing outsourcing acreage and the optimal subsidy levels under both subsidy programs. It also lowers the critical budget thresholds B_f and B_h, thereby narrowing the budget range over which PSP yields higher welfare than FSP. Thus, for a given subsidy budget, the welfare advantage of PSP may disappear when the environmental external cost becomes sufficiently large, although the ranking does not reverse within the present model because the environmental cost is common to outsourced production under both subsidy programs.

Finally, PSP generates a larger increase in farmers' profits per unit of government subsidy expenditure than FSP. When $B \geq B_h$, PSP also generates a larger increase in welfare per unit of subsidy expenditure. These results indicate that the choice of subsidy recipient should be evaluated jointly with fiscal capacity, service-price transmission, and environmental external costs rather than on the basis of a single performance metric.

7.2. Managerial insights

Our study provides the following managerial insights.

(1) The choice of subsidy recipient should jointly consider fiscal capacity and the environmental external costs associated with agricultural production. When the subsidy budget is constrained, PSP can generate higher farmers' profits and welfare than FSP. However, a larger environmental external cost reduces the welfare-maximizing outsourcing acreage and narrows the budget range over which this welfare advantage of PSP exists. Thus, the relative performance of the two subsidy programs should be evaluated according to both the available subsidy budget and the environmental consequences of expanding outsourced production, rather than adopting a uniform subsidy-recipient rule.

(2) Subsidy design should also account for regional production risks and service-provider production efficiency. Greater yield uncertainty reduces farmers' outsourcing acreage and welfare, while farmers' outsourcing decisions also depend on the service provider's production cost advantage. In regions with high production risks, governments may complement outsourcing subsidies with risk-management measures such as agricultural insurance and agricultural infrastructure investment. Improving the production efficiency of service providers can further enhance farmers' willingness to adopt outsourcing services.

(3) The two subsidy programs have different service-price transmission effects and therefore require different supporting measures. Under FSP, part of the subsidy may be captured by the service provider

through a higher service price, whereas PSP reduces the service provider's effective production cost and is associated with a lower service price. Accordingly, when subsidies are provided directly to farmers, governments may strengthen service-price monitoring, benchmark pricing, and information disclosure to limit excessive subsidy capture and ensure that subsidy benefits are effectively transmitted to farmers.

7.3. Limitations and future research directions

This study incorporates environmental external costs through a common per-unit-area cost to examine their effects on outsourcing decisions and subsidy performance. However, broader environmental and socioeconomic effects, such as technology diffusion, land consolidation, input-use efficiency, and labor reallocation, are not explicitly modeled and may further affect the relative performance of FSP and PSP. Future research could endogenize these mechanisms. In addition, incorporating agricultural insurance would help examine how risk-sharing interacts with outsourcing decisions and alternative subsidy programs.

Author contributions

Shuaishuai Fu: Conceptualization, Methodology, Writing-original draft. Ligang Shi: Writing-review & editing, Supervision.

Use of Generative-AI tools declaration

During the preparation of this work, the author(s) did not use any generative artificial intelligence (AI) tools or AI-assisted technologies in the writing process. All content, including the conceptualization, methodology, formal analysis, and writing, was completed solely by the human authors.

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Conflict of interest

There are no relevant financial or non-financial competing interests to declare.

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