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The Impact of Input and Output Farm Subsidies on Farmer Welfare, Income Disparity, and Consumer Surplus

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Abstract. Because of a growing population and shrinking arable land, the world is facing a global food crisis. One important solution could be to subsidize farmers to sustain their production so that they can produce more food for consumers and earn more money for themselves. An efficient subsidy program should also aim to reduce income inequality among farmers, as measured by the Gini coefficient of farmers' income. In this paper, we examine and compare the effects of input and output farm subsidy programs. The input subsidy reduces the farmers' input purchasing costs, whereas the output subsidy reduces the farmers' output processing costs. By considering a continuum of infinitesimal price-taking farmers who are heterogeneous in their average yield rates, our equilibrium analysis of a game-theoretical model yields three results. First, both subsidy schemes reduce the aggregate income inequality measured by the Gini coefficient. However, they create the following "opposite" effects: the input subsidy decreases the income gap among farmers (under mild conditions), whereas the output subsidy increases it. Second, farmers with low yield rates prefer the input subsidy, whereas farmers with high yield rates prefer the output subsidy. Third, the output subsidy scheme is more effective in improving the total farmer income than the input subsidy scheme, whereas the input subsidy scheme is more effective in reducing income disparities and improving consumer surplus than the output subsidy scheme. Our results provide new insights for policymakers who are crafting subsidy schemes.

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Keywords: subsidy scheme • farmer welfare • consumer surplus • Gini coefficient • game theory

1. Introduction

The world is facing an unprecedented food supply crisis. According to the World Food Programme, the number of people facing acute food insecurity has increased from 135 million to 345 million since 2019.[1] The causes of the world food supply crisis include world population growth, political conflicts (e.g., the war in Ukraine), the COVID-19 pandemic, and extreme climate events (e.g., the drought in Somalia and the flood in Pakistan).[2] As noted by Dong (2021), to feed the world's increasing population, there is an urgent need to increase agricultural output by almost 50% by 2050 from what it was in 2012.

As noted, the current food supply crisis is a global phenomenon. Consumers in developed countries are experiencing an inflationary crisis, and consumers in developing countries are experiencing a food shortage–driven humanitarian crisis. To deescalate the consequences of this hunger catastrophe and feed the world despite the fact that resources such as land and water are limited, there is an urgent need to increase food production.

Because of the ongoing sanctions against Russia and its retaliatory trade measures, the cost of fertilizer, which is in short supply, surged by more than 80% in 2022 (Paradis 2022). As fertilizers are becoming too costly for farmers seeking higher yields, farmers are finding themselves in a lose–lose situation in which they both produce and earn less. The situation is direst in developing countries, where people who need to earn a living rely on the farming sector. Fifty percent of India's workforce is in the agricultural sector, in which incomes are meager (Sodhi and Tang 2014). In China, more than 40 million farmers live below the official poverty line (Zhao 2018).

The major policy goals of many governments include alleviating both poverty and income inequality among farmers (United Nations 2018). Farmer income inequality is severe; for example, in the Indian agricultural sector, the Gini coefficient is approximately 0.6 (Chakravorty et al. 2019). To enable poor smallholder farmers in developing countries to sustain their farm operations and produce more, the following root causes of farmer poverty must be addressed: high input purchase costs and high output processing costs. Regarding input costs, quality fertilizers and seeds are often unaffordable to farmers in developing countries (Kwa 2001, Mare et al. 2010), negatively affecting both their crop yields and long-term earnings (Jayan 2017). Regarding output costs, the processing costs associated with harvesting, transportation, and postharvest handling are very high for farmers in developing countries because of the poor infrastructure in those countries.[3]

To enable farmers to produce and harvest more, allow them to feed more people, and alleviate their cost concerns, many governments in developing countries provide input and/or output farm subsidies. Input subsidies are provided to help reduce the purchasing costs of certain inputs. For example, the governments of Mali, Ghana, and Nigeria offer price discounts on designated fertilizers (Wiggins and Brooks 2010, Jayne and Rashid 2013).[4] Output subsidies are provided to mitigate the processing costs of outputs. For example, farmers in India receive government transportation subsidies to defray their transportation-related harvest costs (Roy 2018).[5]

Although input and output subsidy schemes are common, their comparative performance in terms of farmers' incomes, consumer surplus, the income gap, and income inequality are not well understood, especially when smallholder farmers are heterogeneous in terms of their yield rates, which are inherent to their endowed resources. Researchers find mixed empirical results pertaining to the implications of these two subsidy programs. Dorward and Chirwa (2011) and Darko (2015) assert that input subsidies can reduce both income inequality and poverty. However, some skeptics argue the opposite (Blarcom et al. 1993). Chinyamakobvu (2012) claims that output subsidies can improve farmer productivity. However, critics of that position argue that output-based transportation subsidies intensify competition, creating detrimental outcomes for farmers (Ahmed 2011).

Both the mixed empirical results and the ongoing debate motivate us to conduct an analytical exploration of the implications of input and output subsidies. Our intent is to examine and compare the performance (in terms of farmers' incomes, consumer surplus, the income gap, and income inequality) associated with these programs. We pay special attention to farmers' income inequality, which has received considerable attention in many developing countries. Many governments have demonstrated a commitment to reducing income inequality in the rural areas where farmers reside.[6]

With this in mind, we develop a unified modeling framework that includes two parties: the government and a continuum of infinitesimal farmers with heterogeneous yield rates. We use this framework to model the interaction between the government and farmers in the following two-stage game: in the first stage, the government is the "leader" that determines the subsidy scheme, and in the second stage, the heterogeneous farmers are the "followers" who determine their planting quantities. Each farmer chooses the planting quantity that maximizes expected income by taking the subsidy and other farmers' planting decisions into consideration. By anticipating the farmers' optimal planting decisions in response to any given subsidy program, the government selects the optimal subsidy to maximize "net social welfare," which is based on a combination of the following three terms: (a) farmers' total income, (b) consumer surplus, and (c) income inequality (measured in terms of the Gini coefficient among farmers).[7]

Whereas we consider the government's concern about the aggregate measure of income inequality across all farmers, we also examine the "disaggregate measure" of the income gap between farmers with different yield rates, which is an issue of concern to individual farmers in the context of equity (Reyes and Gasparini 2021). By solving our two-stage game, we determine and compare the equilibrium outcomes associated with the two subsidy schemes. Our analysis reveals the following:

1. The input subsidy scheme can generate "contrasting" impacts on low- and high-yield farmers: it can boost low-yield farmers' earnings but hinder high-yield farmers' earnings. In contrast, the output subsidy scheme generates a "similar" impact: it can boost the earnings of both high- and low-yield farmers.

2. The input subsidy scheme "reduces" the income gap between any two farmers with different yield rates (under some mild conditions), but the output subsidy scheme "enlarges" this income gap.

3. The output subsidy scheme performs better than the input subsidy scheme in "increasing" total farmer income, but the input subsidy scheme performs better

than the output subsidy scheme in "reducing" income inequality in terms of the Gini coefficient and "improving" the consumer surplus.

As an extension of our study, we also consider a scenario in which the government offers a "combined" subsidy scheme that utilizes both input and output subsidies simultaneously. Interestingly, we find that the effects of the two subsidies on both the incomes of low-yield farmers and the total incomes of all farmers are "complementary": after the government offers one type of subsidy, the system's performance is further enhanced if the government also offers the other type of subsidy. This complementary effect on the incomes of high-yield farmers and the income gap persists under some conditions. We find that the structure of our optimal combined subsidy scheme depends on the magnitude of the importance the government places on reducing income inequality. Finally, as a robustness check, we extend our analysis to a situation in which planting costs vary across farmers. We find that the results in the base model continue to hold. Overall, our comparative results are informative to policy makers who are choosing a subsidy scheme.

The remainder of this paper is organized as follows. We review the relevant literature in Section 2. In Section 3, we describe our modeling framework and the base model. We present our analysis and the equilibrium outcomes associated with the input and output subsidy schemes in Section 4. Section 5 compares the performances of the two subsidy schemes. For the robustness check, the extensions of our base model are presented in Section 6. Section 7 concludes the paper. All of the proofs are relegated to Online Appendix A.

2. Literature Review

Farmers face challenges ranging from productivity to financial risks. We refer readers to Dong (2021) for a broad perspective of how innovative farming techniques (e.g., climate-smart and precision agriculture) can support sustainable farming because of climate change. Dong (2021) also discusses various issues, such as an inclusive agriculture value chain that leverages the notion of aggregation and infomediation to improve farmer welfare. In terms of ways to reduce financial risks for farmers, Boyabatli et al. (2022) compile a collection of research studies that examine three essential elements of agricultural supply chains: planting and growing, processing and selling, and government interventions. This coedited book investigates different challenges in agricultural supply chain operations, including market information provision, incentive contracts, and market structures for improving farmer and consumer welfare.

Because we examine the impact of farm subsidy programs on farmer welfare, our work is naturally related to the stream of research on socially responsible operations that examines the effectiveness of different mechanisms in alleviating farmer poverty. These mechanisms include the provision of market information (e.g., Chen and Tang 2015, Tang et al. 2015, Liao et al. 2019), the presence of strategic farmers (Hu et al. 2019), the creation of farm cooperatives (e.g., An et al. 2015, He et al. 2018), the strategy of seeding policies (Zhang and Swaminathan 2020), and financing (e.g., Tang et al. 2018, Qian and Olsen 2020, Yi et al. 2021). The referenced studies provide a general framework for evaluating different mechanisms but are not based on a particular crop. For this reason, some researchers investigate milk supply chains (Hsu et al. 2019), contract grain farming (Federgruen et al. 2019), and food chains (Roth and Zheng 2020). Unlike these studies, our intent is to compare the impact of farm subsidy schemes on farmer income inequality.

Because of its subject matter, this paper also belongs to the stream of research on agricultural economics that addresses input and output subsidies. By focusing on only one type of subsidy program, empirical studies investigate whether such a program can incentivize farms to increase their production (e.g., Fox 1956, Xu et al. 2009, Chibwana et al. 2012), reduce farmer inequality in different geographic regions (e.g., Keeney 2009, Smale and Mason 2013, Kilic et al. 2015), and alleviate poverty (e.g., Firdausy 1997, Fan et al. 2008, Mason and Tembo 2015). In contrast, we examine and compare the performance of two commonly used subsidy programs.

In essence, the empirical research stream referenced and the existing analytical studies tend to focus on a single type of subsidy program.[8] For instance, Just et al. (1982) investigate how new technology and government interventions (including credit subsidies, input subsidies, and crop insurance) affect farmers' allocation of land for producing traditional (using old technology) versus modern (using new technology) crops. Alizamir et al. (2019) compare two output price support policies, the price loss coverage (PLC) program and the agriculture risk coverage (ARC) program. By comparing their corresponding equilibrium outcomes, for example, for farmer revenues and consumer surplus, they show that the ARC program is dominated by the PLC program under certain market conditions. Relatedly, Guda et al. (2021) explore a guaranteed support price scheme.

Based on our literature search, only limited studies compare the performances of input and output subsidies. Several empirical studies investigate the effects of these two forms of subsidies on farmers' income distribution. By examining the data associated with rice and jute production in Bangladesh, Ahmed (1978) finds that the country's input (fertilizer) subsidy program is more effective than its output (price support) subsidy program. He also conjectures that Bangladesh's output subsidy program has a greater effect than its input subsidy program on reducing income inequality among farmers with differently sized farms. A study conducted in India by Sidhu and Sidhu (1985) obtains similar results. Parish and McLaren (1982) find that input subsidy schemes are more cost-effective than output subsidy schemes. After analyzing data on rice production in the Philippines, Barker and Hayami (1976) find that a fertilizer (i.e., input) subsidy program is more cost-effective than a price support (i.e., output) subsidy program. In a study focusing on three government interventions (i.e., price supports, cost supports, and yield enhancement), Akkaya et al. (2016) find that cost and price supports return the same performance when their total budgets are a matter of public information. Examining the situation in Turkey, Demirdogen et al. (2016) find that the country's input subsidy program has a stronger effect on farmers' land allocation decisions than the output subsidy program does.

We are unaware of any study that examines farmer income inequality. Recognizing the Chinese and Indian governments' recent interest in developing mechanisms to reduce income inequality, our paper addresses an important social issue. In addition, our paper complements the literature by comparing the effects of input and output subsidies on income inequality across all farmers and the income gap between farmers with different yield rates. In a very recent book chapter, Tang et al. (2022) present their preliminary "coarse" model of a similar problem that is based on the following assumptions: (1) the market is composed of two farmers, (2) both farmers are "price setters" whose output can affect market price, (3) each farmer is subject to a linear production cost, (4) the topic of interest focuses on the income difference between the two farmers, and (5) the government's objective function is based on the total farmer income minus the income gap between the two farmers.

Unlike this book chapter (Tang et al. 2022), our paper is based on a refined model with general, but different, assumptions, which are as follows: (1) the market is composed of a continuum of infinitesimal smallholder farmers; (2) each farmer is a "price taker" so that an individual farmer's output has no impact on the market price although the collective total farmer output has a direct impact on the market price; (3) each farmer is subject to a quadratic production cost; (4) the topic of interest focuses on an aggregate income inequality measure (based on the Gini coefficient) across all the farmers; and (5) the government's objective function is based on a combination of farmer welfare, consumer surplus, and the Gini coefficient. Because our modeling assumptions are fundamentally different from those of Tang et al. (2022) and the government's objective function is expansive, including the aggregate measure of farmer inequality via the Gini coefficient, our analysis and results are very different from theirs. In addition, we conduct robustness checks by considering additional extensions.

Our paper makes the following three contributions. First, we present a unified modeling framework for both subsidy schemes when infinitesimal price-taking farmers are heterogeneous in their average yields. Second, we analyze and compare the effects of input and output subsidies on aggregate farmer income inequality (via the Gini coefficient) and the disaggregate income gap between farmers with different yield rates along with farmer welfare and consumer surplus. Third, we discover the dissimilar effects of these two subsidy schemes with regard to the income gap, income inequality, farmer welfare, and the consumer surplus. Therefore, this study provides new insights into the effectiveness of these subsidy schemes in a manner that can be informative to policy makers who are crafting subsidy schemes.

3. Model Preliminaries

Consider the case in which many risk-neutral smallholder farmers are located in the same geographic region. They grow a single commodity crop and then sell it in the local market.[9] In developing countries, farmers in a given area tend to grow the same crop. For example, in West Bengal, almost 50% of the arable land is allocated to rice production. Although these farmers grow the same crop, they are "heterogeneous" with respect to their endowed resources, such as farming knowledge, soil quality, and water sources. To capture the heterogeneous resources r across many farmers, we model these farmers as a continuum of infinitesimal farmers of market size normalized to one, and we assume that r is uniformly distributed over the interval $[0, 1]$.

3.1. Multiplicative Yield Uncertainty

To capture the link between the endowed resources r of each farmer and the farmer's yield rate so that the yield rate is farmer-specific, we assume that, for each unit of input, the output yield of a farmer with resource r is $Y(r) = \mu(r) \cdot \varepsilon$, where

1. The term $\mu(r)$ represents the mean yield level of a farmer with endowed resources r, where $\mu(r)$ is increasing in r with $\mu(0) = \mu_l$ (the lowest yield rate) and $\mu(1) = \mu_h$ (the highest yield rate). For ease of exposition, we denote M_1 and M_2 as the first and second moments of $\mu(r)$; that is, $M_1 \equiv \int_0^1 \mu(r)dr$ and $M_2 \equiv \int_0^1 (\mu(r))^2 dr$, respectively.

2. The term ε captures the common yield uncertainty (such as the uncertain weather and rainfall that affect farmers located in the same region) with mean $E[\varepsilon] = 1$ and variance $Var[\varepsilon] = \sigma^2$.[10]

Observe that we consider multiplicative (instead of additive) yield uncertainty in our model, as is the standard approach to capturing crop yield uncertainty in the agricultural planning literature (e.g., Kazaz 2004, Xiao et al. 2020, Zhou et al. 2021). Additionally, we consider the common yield uncertainty ε for three reasons. First, in developing countries, such as Turkey, the vast majority of crops, such as olives, are grown in a small geographic area such that the growers face a similar yield uncertainty (Kazaz 2004). Second, common yield uncertainty is a standard assumption for tractability that is widely used in the literature (e.g., Alizamir et al. 2019, Chintapalli and Tang 2021) to capture the correlation of different farmers' uncertain yield rates. Third, smallholder farmers in developing countries usually lack information (Tang et al. 2015). Therefore, it is reasonable to assume that each farmer can only know the farmer's own yield uncertainty and believes that all other farmers have the same yield uncertainty; that is, $E[\varepsilon] = 1$ and $Var[\varepsilon] = \sigma^2$.

3.2. The Farmer's Input Decision, Output Yield, and Earnings

At the start of the sowing season, each farmer r chooses a planting (input) quantity q_r, which then generates an output quantity $Y(r)q_r$, where $Y(r) = \mu(r) \cdot \varepsilon$ with $E[\varepsilon] = 1$ and $Var[\varepsilon] = \sigma^2$. Hence, the total planting (i.e., input) quantity $I = \int_0^1 q_r dr$ and the total harvest (i.e., output) quantity $Q = \int_0^1 Y(r)q_r dr$. Because $Y(r) = \mu(r)\varepsilon$, we rewrite Q succinctly as follows:

$$Q = H \cdot \varepsilon, \text{ where } H = \int_0^1 \mu(r)q_r dr. \tag{1}$$

Here, H is the expected total harvest without accounting for the yield uncertainty ε. Because $E[\varepsilon] = 1$, the expected total harvest (i.e., output) quantity $E[Q] = H$. As we see later, when farmer r determines the farmer's own planting quantity q_r, the farmer forms a belief about H, where H is inferred correctly in equilibrium.

3.2.1. Input and Output Costs. Following the agricultural economics literature (e.g., Hueth and Regev 1974, Chambers 1992), we assume that, associated with the planting quantity q_r, each farmer r incurs a quadratic "input" planting cost $C(q_r)$ that includes costs such as labor, seeds, and fertilizer, where $C(q_r) = \alpha q_r + \beta q_r^2/2$. Here, the second term, β, captures the farmers' effort cost. Furthermore, we assume that the cost parameters α and β are the same for all farmers. This setting is appropriate for growing crops such as snow peas and garlic. For these two crops, the yield rates vary significantly across farmers, but the planting cost remains fairly stable. For example, according to Bhandari et al. (2015), the coefficients of variation (CV) for the yields of snow peas and garlic are 5 and 10 times larger, respectively, than the corresponding CV of their unit costs. (In Section 6, we extend our base model to a situation in which the effort cost coefficient β can vary across farmers.) Similarly, we assume that each farmer incurs the same unit output processing cost t that includes harvesting, storage, and transportation.

3.2.2. Equilibrium Market Price. In developing countries, usually, farmers are smallholders who work fewer than two hectares of land (Sharma 2013). Hence, each individual farmer is a price taker whose output has no impact on the market price. However, the collective total farmer output Q has a direct impact on the market price. For any realized total output Q associated with the realized yield $Y(r) = \mu(r) \cdot \varepsilon$, we assume that the ex post market price satisfies $\tilde{P} = m - bQ$, where m represents the market potential and b indicates the price sensitivity.[11] However, when the farmer decides the planting quantity, the yield $Y(r)$ has not yet been realized, and so the total output quantity Q and the corresponding ex ante market price $\tilde{P}$ are uncertain. By using (1), which has $Q = H \cdot \varepsilon$ and $E[\varepsilon] = 1$, $\tilde{P}$ and its ex ante expected market price satisfy

$$\tilde{P} = m - b \cdot H \cdot \varepsilon, \text{ and } E[\tilde{P}] = m - b \cdot E[Q] = m - bH. \tag{2}$$

3.2.3. Rational Expectations Equilibrium Concept. Following the rational expectations equilibrium concept as illustrated in Liu and van Ryzin (2008), we assume that, through historical observations and past experiences, farmers can form rational expectations about their expected total harvest quantity $E[Q] = H$. Rational expectations are commonly used in the operations management literature (e.g., Swinney 2011) to capture individuals' beliefs about quantity-related measurements (e.g., fill rate, production quantity). This assumption is also widely used in the agricultural economics literature to model farmers' responses to market prices (e.g., Fisher 1982, Liao et al. 2019) and is well-supported by empirical evidence (e.g., Cooley and DeCanio 1977, Goodwin and Sheffrin 1982, Eckstein 1984).

By noting that $\tilde{P} = m - b \cdot H \cdot \varepsilon$, $Y(r) = \mu(r)\varepsilon$, and $E[\varepsilon^2] = 1 + \sigma^2$, each farmer r determines a planting quantity q_r at the start of the sowing season to maximize the farmer's (ex ante) expected income $\pi_r(q_r)$ (i.e., before the farmer's yield $Y(r) = \mu(r)\varepsilon$ is realized), where

$$\begin{aligned}\pi_r(q_r) &= E[(\tilde{P} - t)Y(r)q_r - C(q_r)] \\ &= E[(m - b \cdot H \cdot \varepsilon - t)Y(r)q_r - C(q_r)] \\ &= E[(m - bH\varepsilon - t) \cdot \mu(r)\varepsilon \cdot q_r - C(q_r)] \\ &= (m - b(1+\sigma^2)H - t)\mu(r)q_r - \alpha q_r - \frac{\beta q_r^2}{2}.\end{aligned} \tag{3}$$

3.3. Subsidy Schemes, Income Disparity, and Net Social Welfare

As explained in Section 1, the subsidy schemes studied in this paper are intended to entice farmers to produce and earn more by reducing their operating costs. First, under the input subsidy scheme, the government provides a subsidy δ for each unit of input, such as seeds and fertilizer. Consequently, the unit planting cost is reduced to $\alpha - \delta$, where $\delta \in [0, \alpha]$. Second, under the output subsidy scheme, the government provides a subsidy θ for each unit of output, such as transportation and storage. Therefore, the unit processing cost is reduced to $t - \theta$, where $\theta \in [0, t]$.

Our goal is to examine and compare the impacts of the input and output subsidies on income disparity. Next, we formally define farmer income disparity.

3.3.1. Income Gap and Income Inequality. Farmer income disparity can be measured in two ways. First, from the perspective of individual farmers, peer comparison is key. Thus, individual farmers care about the income gap $\pi_{r_1}(\cdot) - \pi_{r_2}(\cdot)$ between two farmers with endowed resources r_1 and r_2, where $r_1 > r_2$. Second, from the government's perspective, an aggregate measure of income inequality across all farmers is key. This aggregate measure can be captured by the Gini coefficient, which measures the degree of inequality in a population's income distribution (Giorgi and Gigliarano 2016). Next, we elaborate how we derive the Gini coefficient across all farmers.

First, observe that the farmers' total income Π is

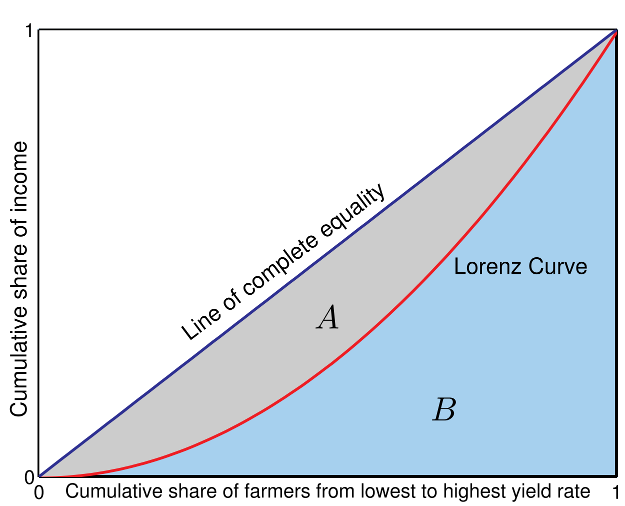
$$\Pi = \int_0^1 \pi_r dr. \tag{4}$$

Then, we determine the Lorenz curve $L(x)$ (Lorenz 1905), which is based on the cumulative share of the total income for the bottom x proportion of farmers as follows:

$$L(x) = \frac{\int_0^x \pi_r dr}{\Pi},$$

where $\pi_r(\cdot)$ is farmer r's expected income as stated in (3).

Figure 1. (Color online) Gini Coefficient



According to Giorgi and Gigliarano (2016), the Gini coefficient, denoted by G, is defined as the ratio of the area between the line of complete equality and the Lorenz curve (i.e., area A) over the total area under the line of equality (i.e., area $A + B$), as depicted in Figure 1. Hence, the Gini coefficient $G = A/(A + B)$. Also, the Gini coefficient can be expressed as

$$G(\cdot) = 1 - 2\int_0^1 L(x)dx = 1 - 2\frac{\int_0^1 \int_0^x \pi_r dr dx}{\int_0^1 \pi_r dr}. \tag{5}$$

3.3.2. The Government's Subsidy Program and Net Social Welfare. Because of limited financial resources, we assume that the budgets for agricultural subsidy programs Ω are earmarked in a manner that is known in advance.[12] Given budget Ω, the government chooses a subsidy level δ for the input subsidy scheme (or θ for the output subsidy scheme) that maximizes the net social welfare (which is defined as follows).

Net social welfare captures three aggregate measures that concern most governments:

1. Farmer welfare, which can be measured by the total farmer income Π as given in (4).
2. Consumer welfare, which can be measured in terms of the expected consumer surplus U. Following the literature (e.g., Alizamir et al. 2019), consumer surplus can be defined as the area under the demand curve and above the market price. By considering Figure 2 and noting that $Q = H \cdot \varepsilon$ and $E[\varepsilon^2] = 1 + \sigma^2$, one can check that the expected consumer surplus is $U = bE[Q^2]/2 = b(1 + \sigma^2)H^2/2$.
3. Income inequality across all farmers, which can be measured in terms of the Gini coefficient G as given in (5).

By combining these three aggregate measures, we can define net social welfare $W(\cdot)$ as

$$W(\cdot) = \Pi(\cdot) + U(\cdot) - \lambda \cdot G(\cdot), \tag{6}$$

where the parameter $\lambda > 0$ reflects the government's level of concern about aggregate income inequality.[13]

Figure 2. (Color online) Consumer Surplus

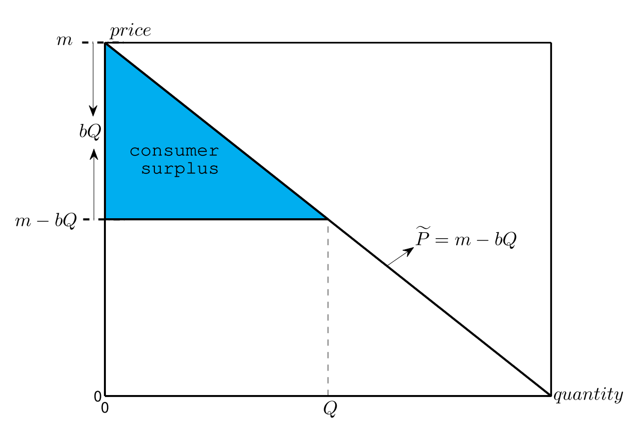


Table 1. List of Notations

Notation	Definition
$\mu(r)$	Mean yield rate of farmer r
(M_1, M_2)	The first and second moment of $\mu(r)$
ε	Common yield uncertainty
$(1, \sigma^2)$	Mean and variance of the common yield uncertainty ε
$Y(r) = \mu(r) \cdot \varepsilon$	Uncertain yield rate of farmer r
q_r	Planting (input) quantity of farmer r (a decision variable)
π_r	Expected income of farmer r
I	Total planting quantity, where $I = \int_0^1 q_r dr$
H	Expected total harvest (output) quantity without accounting for yield uncertainty
Q	Total harvest (output) quantity, where $Q = \int_0^1 \mu(r) q_r dr \cdot \varepsilon = H \cdot \varepsilon$
$C(q_r) = \alpha q_r + \beta q_r^2/2$	Input planting cost of farmer r; α is the unit planting cost and β is the effort cost coefficient
t	Output processing cost
δ	Unit input subsidy (a decision variable)
θ	Unit output subsidy (a decision variable)
$\tilde{P} = m - bQ$	Market price, where m represents market potential and b indicates price sensitivity
U	Expected consumer surplus, where $U = bE[Q^2]/2 = b(1+\sigma^2)H^2/2$
G	Gini coefficient
Ω	Government's earmarked annual budget
λ	The parameter representing the government's level of concern over the aggregate income inequality
Π	Total farmer income
W	Net social welfare

3.3.3. The Sequence of Events.

The sequence of events is as follows. First, in the presence of a given earmarked budget Ω, the government decides which subsidy scheme to adopt (the input or output subsidy scheme) along with the corresponding subsidy level (the input-based unit subsidy δ or the output-based unit subsidy θ). Next, observing the offered subsidy scheme and the associated subsidy level, each farmer r chooses the planting (input) quantity q_r and, after harvesting, sells the output quantity $Y(r)q_r$ in the market. Then, each farmer's income, the total farmer income Π, the farmer income gap, farmer income inequality G, and the consumer surplus U are realized along with the net social welfare W given in (6).

To analyze the sequential game associated with each subsidy program, we use backward induction to derive the equilibrium outcomes associated with each subsidy scheme. For ease of exposition, we use the tilde "~" to indicate the equilibrium outcome. For instance, $\tilde{q}_r$ represents the equilibrium planting quantity of farmer r. Table 1 summarizes the notations used in our paper.

4. Equilibrium Analysis

In this section, we derive the equilibrium outcomes under the input and output subsidy schemes by considering the sequential game as explained in Section 3. Backward induction is applied to ensure the subgame perfection.

4.1. Input Subsidies

Under the input subsidy scheme, we first determine each farmer r's best response planting quantity $q_r(\delta)$ for a given unit input subsidy δ that takes other farmers' planting quantities into consideration. Next, we derive the government's optimal subsidy level decision δ^* that maximizes the net social welfare W given in (6) subject to an earmarked budget Ω.

4.1.1. Infinitesimal Farmer's Best Response Production Decision $q_r(\delta)$.

Given input subsidy δ, the effective unit planting cost borne by each farmer with resources r is reduced from α to $(\alpha - \delta)$ so that the farmer's expected income $\pi_r(\cdot)$, given in (3), can be rewritten as

$$\pi_r(q_r) = (m - b(1+\sigma^2)H - t)\mu(r)q_r - (\alpha - \delta)q_r - \frac{\beta q_r^2}{2}. \tag{7}$$

Because each infinitesimal farmer r is a price taker, the farmer's individual production quantity q_r is too small to influence the expected market price $E[\tilde{P}]$, given in (2), even though the collective expected total output of all farmers, $E[Q](=H)$, has a direct impact on $E[\tilde{P}]$. Hence, based on the common belief about H explained in Section 3.2, each farmer r determines the farmer's own planting quantity q_r that maximizes the farmer's expected income $\pi_r(\cdot)$ given in (7). By noting that $\pi_r(q_r)$ is concave in q_r, we can use the first order condition to determine farmer r's planting quantity $q_r(\delta)$ and the resulting income $\pi_r(\delta)$, which yields

$$q_r(\delta) = \frac{(m - b(1+\sigma^2)H - t)\mu(r) - \alpha + \delta}{\beta} \text{ and}$$
$$\pi_r(\delta) = \frac{\beta \cdot (q_r(\delta))^2}{2}. \tag{8}$$

Note that H in (8) is unknown for now, but it is consistent with the equilibrium expected total harvest quantity attributable to farmers' rational expectations as explained

Table 2. Equilibrium Outcomes for a Given Per-Unit Input Subsidy δ

Farmer r's planting quantity	$\tilde{q}_r(\delta)=\frac{(a\beta+(\alpha-\delta)bM_1(1+\sigma^2))\mu(r)}{\beta(\beta+M_2\cdot b(1+\sigma^2))}-\frac{\alpha-\delta}{\beta}$
Expected total harvest quantity	$E[\tilde{Q}(\delta)]=\tilde{H}(\delta)=\frac{aM_2-M_1(\alpha-\delta)}{\beta+M_2\cdot b(1+\sigma^2)}$
Farmer r's expected income	$\tilde{\pi}_r(\delta)=\frac{\beta\cdot(\tilde{q}_r(\delta))^2}{2}$

in Section 3.2. Substituting $q_r(\delta)$ into (1), the right-hand side of (1) is also a function of H. By solving this resulting equation in terms of H, we can obtain the equilibrium expected total harvest quantity based on the concept of rational expectations.

Recall from Section 3 that $M_1=\int_0^1\mu(r)dr$ and $M_2=\int_0^1\mu(r)^2dr$. Then, by substituting $\tilde{H}(\delta)$ into (8) and letting $a\equiv m-t$ (for ease of exposition), we can obtain the farmers' equilibrium planting decisions for any given input subsidy δ, which are summarized in Table 2. Here, we assume that the market potential m is large enough (i.e., $a=m-t$ is large enough) to ensure that all farmers' planting quantities $\tilde{q}_r(\delta)$ in Table 2 are positive (i.e., $\tilde{q}_r(\delta)>0$ for $r\in[0,1]$).

We now examine the comparative statics of those equilibrium outcomes as stated in Table 2 in the following proposition.

Proposition 1 (Comparative Statics of Equilibrium Outcomes When the Input Subsidy δ Is Given). *Given the per-unit input subsidy δ, the equilibrium outcomes under the input subsidy scheme possess the following properties:*

1. *(Impact of input subsidy δ on farmer production and income) There exists a threshold $\tau:=b(1+\sigma^2)(M_1\mu_h-M_2)$ such that, if the effort cost coefficient $\beta\geq\tau$, then farmer r's planting quantity $\tilde{q}_r(\delta)$, the expected harvest $\mu_r\tilde{q}_r(\delta)$, and the expected income $\tilde{\pi}_r(\delta)$ are increasing in δ for all $r\in[0,1]$. However, if $\beta<\tau$, there exists a threshold $\bar{r}$ such that $\tilde{q}_r(\delta)$, $\mu_r\tilde{q}_r(\delta)$, and $\tilde{\pi}_r(\delta)$ are increasing in δ if and only if $r<\bar{r}$.*

2. *(Impact of endowed resources r) Consider two farmers with endowed resources r_1 and r_2, respectively. If $r_1>r_2$, then the farmer with more endowed resources r_1 (which results in a higher yield) plants, harvests, and earns more than the farmer with fewer endowed resources r_2; that is, $\tilde{q}_{r_1}(\delta)>\tilde{q}_{r_2}(\delta)$, $\mu(r_1)\tilde{q}_{r_1}(\delta)>\mu(r_2)\tilde{q}_{r_2}(\delta)$, and $\tilde{\pi}_{r_1}(\delta)>\tilde{\pi}_{r_2}(\delta)$. If $\beta<\tau$ and $r_1>\bar{r}$, these two farmers' income gap (i.e., $\tilde{\pi}_{r_1}(\delta)-\tilde{\pi}_{r_2}(\delta)$) decreases in δ.*

3. *(Impact of input subsidy δ on farmer income inequality G) Income inequality measured in terms of the Gini coefficient $\tilde{G}(\delta)$ decreases in δ.*

4. *(Impact of yield uncertainty σ) Farmer r's planting quantity $\tilde{q}_r(\delta)$, the expected harvest $\mu_r\tilde{q}_r(\delta)$, the expected income $\tilde{\pi}_r(\delta)$, and the income gap $\tilde{\pi}_{r_1}(\delta)-\tilde{\pi}_{r_2}(\delta)$ $(r_1>r_2)$ decrease in yield uncertainty σ. The Gini coefficient $\tilde{G}(\delta)$, however, increases in σ.*

The former part of the first statement of Proposition 1 is intuitive: when the effort cost coefficient is large ($\beta\geq\tau$), all farmers plant, harvest, and earn more with a higher level of input subsidies. The latter part of the first statement, however, is more nuanced. It reveals that, when the effort cost coefficient $\beta<\tau$, by helping farmers reduce their unit planting cost from α to $(\alpha-\delta)$, the input subsidy incentivizes only low-yield farmers with fewer endowed resources (i.e., $r<\bar{r}$) to plant, harvest, and earn more. In contrast, high-yield farmers with more endowed resources (i.e., $r\geq\bar{r}$) are discouraged from producing more to earn more. The intuition behind this result is as follows. First, observe from (2) that the expected market price $E[\tilde{P}]$ decreases with the expected total harvest quantity H. Second, when the effort cost β is low, all farmers have an incentive to produce more. Because all farmers receive the same per-unit input subsidy δ, low-yield farmers with fewer endowed resources have strong incentive to plant more to earn more because their low-yield harvest will not significantly affect the market price. Anticipating this behavior and the fact that farmers with more resources have higher yield rates (because $\mu(r)$ is increasing in r), high-yield farmers with more endowed resources are reluctant to plant more because their high-yield harvests will cause the market price to drop substantially, which, in turn, will significantly decrease their income. Because high-yield farmers suffer more from price decreases, they plant less as the input subsidy δ increases.

Next, the second statement of Proposition 1 implies that, relatively speaking, because of the yield advantage, a farmer with more resources plants, harvests, and earns more than a farmer with fewer resources, leading to an income gap between the farmers. It further reveals that, when the effort cost coefficient $\beta<\tau$ and the high-yield farmer's resource endowment are relatively large (i.e., $r_1>\bar{r}$), a higher input subsidy level narrows this income gap because the high-yield farmer r_1 plants and harvests less as implied by the latter part of the first statement. These observations naturally lead to the third statement of Proposition 1: a higher input subsidy level always reduces income inequality as measured by the Gini coefficient.

Finally, the last statement of Proposition 1 shows that, with an increase in yield uncertainty, farmers produce and earn less as expected. However, the following result is more subtle: the income gap is decreasing, whereas the Gini coefficient is increasing in σ. This result can be explained as follows. First, between any two farmers r_1 and r_2 with $r_1>r_2$, (8) reveals that the high-yield farmer r_1, who has a higher expected yield rate $\mu(r_1)$, reduces planting quantity $q_{r_1}(\delta)$ more substantially than the low-yield farmer r_2 does. Combining this observation with $\pi_r(\delta)$ given in (8), we can conclude that the high-yield farmer r_1's income decreases more rapidly with the increase in yield uncertainty than the low-yield farmer r_2 does, leading to a smaller income gap. Although a higher yield uncertainty decreases the income gap, the aggregate income inequality measured by the Gini coefficient increases. The underlying reason is that, as yield uncertainty increases, the numerator of the second term of the Gini coefficient given in (5) decreases faster than its denominator does.

4.1.2. The Optimal Government Subsidy Decision δ^*. We now determine the government's optimal per-unit input subsidy δ^*. Anticipating farmer r's best response planting decision $\tilde{q}_r(\delta)$ as given in Table 2, the government chooses δ^*, which maximizes its net social welfare $\tilde{W}(\delta)$ as given in (6) by solving

$$\max_{\delta} \tilde{W}(\delta) = \max_{\delta}\{\tilde{\Pi}(\delta) + \tilde{U}(\delta) - \lambda \tilde{G}(\delta)\}, \tag{9}$$

$$s.t. \quad \delta \cdot \tilde{I}(\delta) \le \Omega, \tag{10}$$

where (10) is the budget constraint that depends on the farmers' total planting quantity $\tilde{I}(\delta) = \int_0^1 \tilde{q}_r(\delta) dr$.

By utilizing the first statement of Proposition 1, we can show that the total input-based subsidy $\delta \cdot \tilde{I}(\delta) = \delta \cdot \int_0^1 \tilde{q}_r(\delta) dr$ is increasing in subsidy level δ. By using this observation and the fact that the net social welfare $\tilde{W}(\delta)$ given in (9) is increasing in δ as stated in the next proposition, we conclude that the budget constraint (10) must be binding at the optimal solution. When the budget constraint (10) is binding and as $\delta \cdot \tilde{I}(\delta)$ is increasing in δ, we can conclude that, as the earmarked budget Ω increases, the optimal input subsidy δ^* also increases. To avoid an unreasonable case in which δ^* is higher than the unit planting cost α so that the government is essentially paying the farmers to farm, we assume that budget Ω is moderate to ensure that $\delta^* < \alpha$.[14] We then have the following.

Proposition 2. *Under the input subsidy scheme, the net social welfare $\tilde{W}(\delta)$ is increasing in δ. In equilibrium, the budget constraint* (10) *is binding, and the optimal input-based unit subsidy δ^* provided by the government satisfies*

$$\delta^* = \frac{\left\{ \begin{array}{c} -(a\beta M_1 - \triangle\alpha) \\ + \sqrt{(a\beta M_1 - \triangle\alpha)^2 + 4\triangle\beta(\beta + M_2 \cdot b(1+\sigma^2))\Omega} \end{array} \right\}}{2\triangle}, \tag{11}$$

where $\triangle = \beta + b(1+\sigma^2)(M_2 - M_1^2)$. Furthermore, the optimal input subsidy δ^* increases in yield uncertainty σ.

To interpret Proposition 2, we first make two observations. First, recall from the last statement of Proposition 1 that the planting quantity $\tilde{q}_r(\delta)$ is decreasing in yield uncertainty σ so that the farmers' total planting quantity $\tilde{I}(\delta) = \int_0^1 \tilde{q}_r(\delta) dr$ is also decreasing in σ. Second, as noted, the total input-based subsidy $\delta \cdot \tilde{I}(\delta) = \delta \cdot \int_0^1 \tilde{q}_r(\delta) dr$ is increasing in the subsidy level δ. Combining these two observations and the fact that the budget constraint $\delta \cdot \tilde{I}(\delta) \le \Omega$ is binding at the optimal solution, we can conclude that the optimal input subsidy δ^* increases in the yield uncertainty σ as stated in Proposition 2.

In addition to the technical explanation, Proposition 2 is based on the following intuition through the government's anticipation of the farmers' best response planting quantities as stated in Proposition 1. To elaborate, recall from the last statement of Proposition 1 that, with an increase in yield uncertainty, all farmers produce, harvest, and earn less, which leads to a lower net social welfare W because of the lower expected farmer total income Π, lower consumer surplus U, and higher Gini coefficient G. To counteract this negative impact on W, it would be optimal for the government to offer a higher subsidy δ (subject to the budget constraint) as a way to induce the farmers to plant more so that they can earn more.

In summary, the input subsidy scheme benefits low-yield farmers but may hurt high-yield farmers as shown in the first statement of Proposition 1. In addition, Proposition 1 reveals that the input subsidy scheme reduces the income inequality via the Gini coefficient and can narrow the income gap under some mild conditions. Proposition 2 further reveals that the budget constraint is always binding and the optimal input-based unit subsidy δ^* increases in the yield uncertainty σ. However, the question remains as to whether these results continue to hold under the output subsidy scheme. Next, we examine this issue.

4.2. Output Subsidies

Under the output subsidy scheme, the government provides a subsidy θ for each unit of harvest output so that a farmer r who produces $\mu(r)$ expected units of output receives an output subsidy $\theta \cdot \mu(r)$. Hence, a farmer with more endowed resources r receives a higher output subsidy. This is in sharp contrast to the result under the input subsidy scheme in which all farmers, regardless of their endowed resources, receive the same per-unit subsidy δ. This contrast is instrumental to our later explanation of why the output and input subsidy programs generate different performances.

4.2.1. Infinitesimal Farmer's Best Response Production Decision $q_r(\theta)$. Following the same approach as that presented in Section 4.1.1, we now derive farmer r's best response planting decision given the output subsidy θ. Farmer r's marginal revenue is increased from $\tilde{P} - t$ to $\tilde{P} - (t - \theta)$ under the output subsidy scheme.[15] Hence, farmer r's expected income $\pi_r(\cdot)$ as given in (3) can be rewritten as

$$\pi_r(q_r) = (m - b(1+\sigma^2)H - (t - \theta))\mu(r)q_r - \alpha q_r - \frac{\beta q_r^2}{2}. \tag{12}$$

As before, each infinitesimal farmer r's output quantity $\mu(r)q_r$ is too small to influence the market price (although

Table 3. Equilibrium Outcomes for a Given Per-Unit Output Subsidy θ

Farmer r's planting quantity	$\tilde{q}_r(\theta) = \frac{((a+\theta)\beta+\alpha b M_1(1+\sigma^2))\mu(r)}{\beta(\beta+M_2\cdot b(1+\sigma^2))} - \frac{\alpha}{\beta}$
Expected total harvest quantity	$E[\tilde{Q}(\theta)] = \tilde{H}(\theta) = \frac{(a+\theta)M_2 - M_1\alpha}{\beta+M_2\cdot b(1+\sigma^2)}$
Farmer r's expected income	$\tilde{\pi}_r(\theta) = \frac{\beta(\tilde{q}_r(\theta))^2}{2}$

the collective expected total harvest quantity of all farmers has a direct impact). Because $\pi_r(q_r)$ is concave in q_r, it can easily be shown that farmer r's best response planting quantity $q_r(\theta)$ and the corresponding income $\pi_r(\theta)$ are

$$q_r(\theta) = \frac{(m - b(1+\sigma^2)H - t + \theta)\mu(r) - \alpha}{\beta} \quad \text{and}$$

$$\pi_r(\theta) = \frac{\beta \cdot (\tilde{q}_r(\theta))^2}{2}. \tag{13}$$

Recall that $a = m - t$. By using the same approach as that presented in Section 4.1.1, we obtain the equilibrium outcomes as shown in Table 3.

Proposition 3 (Comparative Statics of Equilibrium Outcomes When the Output Subsidy θ Is Given). *Given the per-unit output subsidy θ, the equilibrium outcomes under the output subsidy scheme have the following properties:*

1. *(Impact of output subsidy θ on farmer production and income) Farmer r's best response planting quantity $\tilde{q}_r(\theta)$, expected harvest quantity $\mu(r)\cdot\tilde{q}_r(\theta)$, and expected income $\tilde{\pi}_r(\theta)$ are all increasing in θ.*
2. *(Impact of endowment resources r) Consider two farmers with endowed resources of r_1 and r_2, respectively. If $r_1 > r_2$, then the farmer with more endowed resources r_1 plants, harvests, and earns more than the farmer with fewer endowed resources r_2; that is, $\tilde{q}_{r_1}(\theta) > \tilde{q}_{r_2}(\theta)$, $\mu(r_1)\tilde{q}_{r_1}(\theta) > \mu(r_2)\tilde{q}_{r_2}(\theta)$, and $\tilde{\pi}_{r_1}(\theta) > \tilde{\pi}_{r_2}(\theta)$. Moreover, the income gap between these two farmers (i.e., $\tilde{\pi}_{r_1}(\theta) - \tilde{\pi}_{r_2}(\theta)$) is increasing in θ.*
3. *(Impact of output subsidy θ on farmer income inequality G) The income inequality measured in terms of the Gini coefficient $\tilde{G}(\theta)$ is decreasing in θ.*
4. *(Impact of yield uncertainty σ) Farmer r's planting quantity $\tilde{q}_r(\theta)$, the expected harvest $\mu(r)\tilde{q}_r(\theta)$, the expected income $\tilde{\pi}_r(\theta)$, and the income gap $\tilde{\pi}_{r_1}(\theta) - \tilde{\pi}_{r_2}(\theta)$ $(r_1 > r_2)$ decrease in yield uncertainty σ. The Gini coefficient $\tilde{G}(\theta)$, however, increases in σ.*

Proposition 3 resembles Proposition 1 (which is associated with the input subsidy scheme) except for the first statement and the income gap as set forth in the second statement. To avoid repetition, our discussion focuses on these two differences.

First, recall from the first statement of Proposition 1 that the impact of the unit input subsidy δ on farmer r's planting decision and earnings depends on the effort cost coefficient β and the farmer's endowed resources r. However, the impact of the unit output subsidy θ on farmer r does not hinge upon either β or r. This is because, regardless of the effort cost coefficient β and the endowed resources r, a farmer is incentivized to plant more so that the farmer can produce more and take advantage of a higher output subsidy θ. Next, as explained earlier, a farmer with more endowed resources r receives a higher output subsidy under the output subsidy scheme because of the farmer's higher harvest output. In contrast, all farmers, regardless of their endowed resources, receive the same per unit subsidy δ under the input subsidy scheme. This contrast is the key reason for the difference between the first statements of Propositions 1 and 3. As the output subsidy θ increases, a farmer with more endowed resources r receives a larger subsidy than a farmer with fewer endowed resources. For this reason, the second statement of Proposition 3 reveals that the income gap $\tilde{\pi}_{r_1}(\theta) - \tilde{\pi}_{r_2}(\theta)$ between any two individual farmers r_1 and r_2 increases with the output subsidy θ.[16] As a whole, however, the third statement of Proposition 3 asserts that the aggregate income inequality (i.e., the Gini coefficient) decreases with the output subsidy θ. The underlying force driving this result is that, as θ increases, each farmer's income increases as set forth in the first statement so that the Lorenz curve (as shown in Section 3.3) shifts upward, bringing it closer to the line of complete equality (i.e., the 45° line). Consequently, the Lorenz curve $L(x)$ becomes larger, and thus, the Gini coefficient $G(.)$ decreases as the output subsidy θ increases.

4.2.2. The Optimal Government Subsidy Decision θ^*.

We now determine the optimal per-unit output subsidy θ^* for the government. Anticipating farmer r's best response planting decision $\tilde{q}_r(\theta)$ as given in Table 3, the government chooses the optimal output subsidy θ^* that maximizes the net social welfare $\tilde{W}(\theta)$ as stated in (6) by solving

$$\max_{\theta} \tilde{W}(\theta) = \max_{\theta}\{\tilde{\Pi}(\theta) + \tilde{U}(\theta) - \lambda\tilde{G}(\theta)\}, \tag{14}$$

$$s.t. \quad \theta \cdot E[\tilde{Q}(\theta)] \le \Omega, \tag{15}$$

where (15) is the budget constraint that depends on the farmers' expected total harvest quantity $E[\tilde{Q}(\theta)](= \tilde{H}(\theta))$.

By utilizing the results stated in Proposition 3, it can be easily verified that both the expected total output-based subsidy $\theta \cdot E[\tilde{Q}(\theta)]$ and the net social welfare $\tilde{W}(\theta)$ increase with the output subsidy θ as stated in the next proposition. This observation implies that the budget constraint (15) must be binding at the optimal solution. Because Ω represents the annual budget, the unused budget in one year can be carried over to the following year. Therefore, although the binding budget constraint (15) holds in expectation, it can balance out in the long run as articulated by other researchers in the operations management literature (e.g., Yu et al. 2020, Arifoglu and Tang 2022, Shi et al. 2022). For example, in Thailand, 9.5% of the fiscal year 2017 budget and 9.2% of the fiscal year 2018 budget were unused and carried over to the next year. Despite the carryover of the unused budget in these two years, the Thai government has an established track record of fiscal control and maintaining its fiscal balance from 2015 to 2019 (Blazey et al. 2021). By considering the binding budget constraint, we can obtain the following.

Proposition 4. *Under the output subsidy scheme, the net social welfare $\tilde{W}(\theta)$ is increasing in θ. In equilibrium, the budget constraint (15) is binding, and the government's optimal output subsidy θ^* satisfies*

$$\theta^* = \frac{\left\{\begin{matrix} -(aM_2-\alpha M_1) \\ +\sqrt{(aM_2-\alpha M_1)^2+4M_2\Omega(\beta+M_2 b(1+\sigma^2))} \end{matrix}\right\}}{2M_2}. \tag{16}$$

Furthermore, the optimal output subsidy θ^* increases in yield uncertainty σ.

Proposition 4 shows that the government should offer a higher output-based per-unit subsidy when yield uncertainty σ increases. This result is analogous to that of Proposition 2 and can be explained in the same manner. To avoid repetition, we omit the details.

5. Comparative Analysis: Input vs. Output Subsidies

Armed with our results as stated in Propositions 1–4, we now compare the equilibrium outcomes under the optimal input subsidy δ^* against the equilibrium outcomes under the optimal output subsidy θ^*. Our direct comparisons yield the following proposition.

Proposition 5 (Equilibrium Outcome Comparison). *By comparing the equilibrium outcomes under the optimal input subsidy δ^* with those under the optimal output subsidy θ^*, we have the following:*

1. *(Farmer's planting, harvesting, and income) There exists a threshold $\hat{r}$ such that a farmer with endowed resources r plants, harvests, and earns more under the optimal output subsidy θ^* than under the optimal input subsidy δ^* if and only if $r > \hat{r}$. In other words, $\tilde{q}_r(\theta^*) > \tilde{q}_r(\delta^*)$, $\mu(r)\tilde{q}_r(\theta^*) > \mu(r)\tilde{q}_r(\delta^*)$, and $\tilde{\pi}_r(\theta^*) > \tilde{\pi}_r(\delta^*)$ if and only if $r > \hat{r}$.*
2. *(Total planting and total harvesting) The optimal input subsidy δ^* induces both a higher total planting quantity and a higher total expected harvest output than the optimal output subsidy θ^*; that is, $\tilde{I}(\delta^*) > \tilde{I}(\theta^*)$, and $E[\tilde{Q}(\delta^*)] > E[\tilde{Q}(\theta^*)]$.*
3. *(Total farmer income and total consumer surplus) The optimal output subsidy θ^* gives rise to a higher total farmer income, whereas the optimal input subsidy δ^* gives rise to a higher total consumer surplus; that is, $\tilde{\Pi}(\theta^*) > \tilde{\Pi}(\delta^*)$ and $\tilde{U}(\delta^*) > \tilde{U}(\theta^*)$.*
4. *(Income gap and income inequality) The optimal output subsidy θ^* leads to a higher income gap between any two individual farmers with endowed resources r_1 and r_2 $(r_1 > r_2)$, respectively, and a higher aggregate income inequality measured by the Gini coefficient than the optimal input subsidy δ^*; that is, $\tilde{\pi}_{r_1}(\theta^*) - \tilde{\pi}_{r_2}(\theta^*) > \tilde{\pi}_{r_1}(\delta^*) - \tilde{\pi}_{r_2}(\delta^*)$ and $\tilde{G}(\theta^*) > \tilde{G}(\delta^*)$.*

We now interpret Proposition 5. First, because of the existence of the threshold $\hat{r}$, the first statement of Proposition 5 implies that high-yield farmers (with $r > \hat{r}$) and low-yield farmers (with $r \le \hat{r}$) have opposing preferences: low-yield farmers prefer the input subsidy scheme δ^*, whereas high-yield farmers prefer the output subsidy scheme θ^*. Recall from Proposition 3 that, when subsidies are based on output, every farmer, regardless of the farmer's endowed resources r, is incentivized to plant more so that the farmer can produce more and take advantage of a higher output subsidy θ to earn more. In contrast, when subsidies are based on input, all farmers receive the same per-unit input-based subsidy. Proposition 1 asserts that only the farmers with low yield rates find the input subsidy scheme to be beneficial when the effort cost coefficient β is low. This difference helps explain the result of the first statement.

Next, recall from the first statement of Propositions 1 and 3 that, relatively speaking, the input subsidy scheme gives the low-yield farmers stronger incentives to increase their planting. This is also confirmed by the first statement of Proposition 5. Consequently, the input subsidy scheme δ^* outperforms the output subsidy scheme θ^* in terms of coaxing farmers to plant more so as to harvest more. However, harvesting more leads to a lower market price, which increases the consumer surplus but reduces the total farmer income. Consequently, the total farmer income is lower under the input subsidy scheme δ^* than under the output subsidy scheme θ^*.

Finally, the last statement of Proposition 5 implies that the output subsidy scheme θ^*, compared with the input subsidy scheme δ^*, both widens the income gap between two individual farmers with different endowed resources and increases farmer income inequality in terms of the Gini coefficient. These are the natural consequences of the first statement of Proposition 5.

5.1. Impact of the Extent of the Government's Concern About Income Inequality

Our model is predicated on the government's concern about farmer income inequality through the Gini coefficient $G(\cdot)$ as given in (5). This concern is also captured by the weight λ assigned to $G(.)$ in the net social welfare function $W(.)$ as defined in (6). We now utilize the results stated in Propositions 1–4 to examine how the extent of the government's concern about farmer income inequality λ affects its preferences concerning the two subsidy schemes. By comparing the optimal net social welfare $\tilde{W}(\delta^*)$ and $\tilde{W}(\theta^*)$ given in (9) and (14) under the two subsidy schemes, we have the following.

Proposition 6 (Subsidy Scheme Selection). *There exists a threshold $\hat{\lambda}$[17] such that the government prefers the output subsidy scheme if $\lambda \le \hat{\lambda}$ and the input subsidy scheme otherwise.*

Proposition 6 indicates that the input subsidy scheme should only be adopted when the government places sufficient emphasis (i.e., when $\lambda > \hat{\lambda}$) on reducing farmer income inequality in terms of the Gini coefficient. The underlying reason for this result is as follows: the input subsidy scheme δ^* offers an equitable subsidy regardless of the farmer's endowed resources r; in contrast, the output subsidy scheme θ^* is more beneficial to farmers with high yield rates. Accordingly, farmer income inequality is decreased by the input subsidy scheme as shown in the last statement of Proposition 5. We can also show that the sum of the total farmer income and consumer surplus under the output subsidy scheme θ^* is higher than it is under the input subsidy scheme δ^* (see the proof of Proposition 6). Thus, when the government has serious concerns about farmer income inequality, the input subsidy scheme is preferable.

5.2. The Impact of Yield Uncertainty: A Numerical Analysis

Proposition 5 summarizes the comparative results of the equilibrium outcomes under the optimal input subsidy δ^* and the optimal output subsidy θ^*. We now examine how these comparative results change as the yield uncertainty σ increases. However, this analysis is intractable because of the complex expressions of the optimal input subsidy δ^* and the optimal output subsidy θ^* given in (11) and (16). Thus, we must resort to numerical studies to investigate how farmers' yield uncertainty σ affects the comparative results stated in Proposition 5.

In our numerical studies, we use the results of regression on corn price and the quadratic cost in the U.S. market provided by Alizamir et al. (2019). We set $m = 11.67$, $b = 2 * 10^{-11}$, and $\beta = 0.00036$.[18] For the unit cost, we set $t = 1$ and $\alpha = 1.88451$.[19] For the mean yield rate $\mu(r)$, we consider the linear function $\mu(r) = (\mu_h - \mu_l)r + \mu_l$. According to Egli and Hatfield (2014), the yield gap of corn ranges from 44% to 84%. This observation motivates us to fix $\mu_h = 0.8$ and vary μ_l from 0.5 to 0.75 with a step length of 0.01. Regarding the earmarked budget Ω, we vary Ω from 1,000 to 5,000 with a step length of 500. By examining more than 2,000 different combinations of these parameter values, we find that the effects of σ^2 on the comparative analysis results are similar.

We now present a sample of our results. As an example, consider the case in which $\mu_l = 0.5$ and $\Omega = 5{,}000$. The numerical results are depicted in Figure 3. First, recall from Proposition 5 that the output subsidy scheme benefits high-yield farmers, whereas the input subsidy scheme benefits low-yield farmers. Figure 3(a) and (b), indicates that a higher yield uncertainty increases (decreases) high-yield (low-yield) farmers' preference for the output (input) subsidy scheme. Second, Figure 3(c)–(f), implies that a higher yield uncertainty enhances the advantages of the two subsidy schemes. With an increase in yield uncertainty, the input subsidy scheme becomes more effective in increasing the production and consumer surplus and reducing the income inequality measured by the Gini coefficient, whereas the output subsidy scheme becomes more effective in increasing the total farmer income.

6. Extensions

In this section, we present two extensions of our base model. First, we extend our analysis to the scenario in which the government provides both input and output subsidies simultaneously. Second, we consider the scenario in which the government has different levels of concern about the total farmer income and the consumer surplus.

6.1. A Combined Input and Output Subsidy Program

We now consider a case in which the government offers a combined subsidy scheme by providing both input and output subsidies. An input subsidy δ per unit of the planting quantity together with an output subsidy θ per unit of the harvest output are provided to each farmer. Because the derivation is routine and similar to that in Section 4, we omit the unnecessary details for the sake of brevity.

6.1.1. Infinitesimal Farmer's Best Response Production Decision $q_r(\delta, \theta)$. Consider a combined per-unit input and output subsidy scheme (δ, θ). Then, each farmer's unit input cost is reduced to $\alpha - \delta$, and the unit output cost is reduced to $t - \theta$. Hence, farmer r's expected income $\pi_r(\cdot)$ given in (3) can be rewritten as

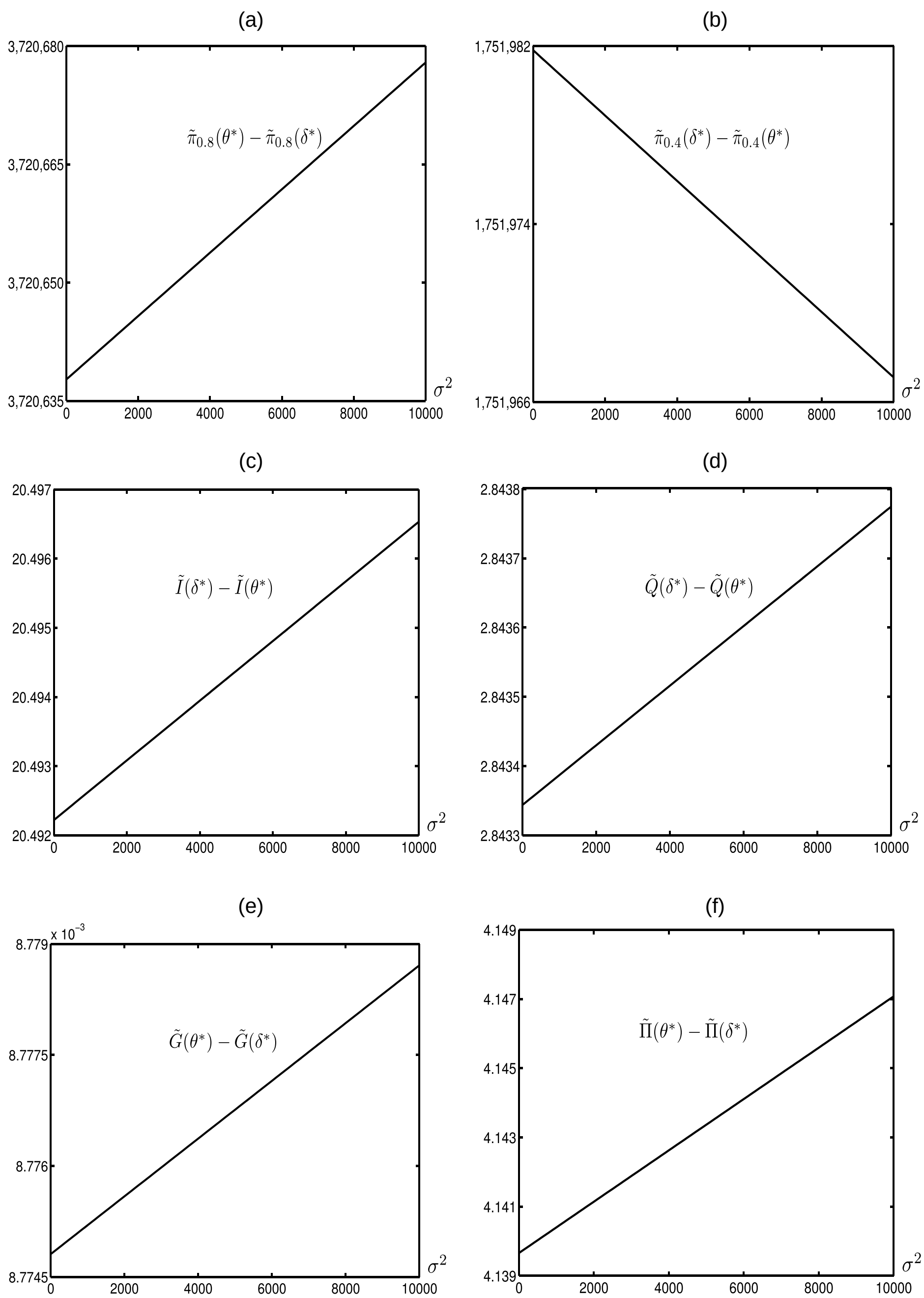
$$\pi_r(q_r) = (m - b(1+\sigma^2)H - t + \theta)\mu(r)q_r - (\alpha - \delta)q_r - \frac{\beta}{2}q_r^2. \tag{17}$$

Again, each infinitesimal farmer r's output quantity $\mu(r)q_r$ is too small to influence the market price (although the collective expected total harvest quantity of all farmers has a direct impact on that price). Because $\pi_r(q_r)$ is concave in q_r, it can be easily shown that farmer r's best response planting quantity $q_r(\delta, \theta)$ and the resulting income $\pi_r(\delta, \theta)$ are

$$q_r(\delta, \theta) = \frac{(m - b(1+\sigma^2)H - t + \theta)\mu(r) - \alpha + \delta}{\beta} \quad \text{and}$$

$$\pi_r(\delta, \theta) = \frac{\beta \cdot \left(\tilde{q}_r(\delta, \theta)\right)^2}{2}. \tag{18}$$

Figure 3. The Impact of Yield Uncertainty



Recall that $a = m - t$. By applying the concept of rational expectations and using the same approach as presented in Section 4.1.1, we obtain the equilibrium outcomes as shown in Table 4.

If we were to denote $\acute{a} = a + \theta$ and $\acute{\alpha} = \alpha - \delta$, then the equilibrium outcomes listed in Table 4 would degenerate to those of their counterparts listed in Tables 2 and 3, respectively. Therefore, the results stated in Propositions 1 (for the input subsidy scheme) and 3 (for the output subsidy scheme) remain intact under the combined subsidy scheme. Next, we examine the joint impact of (δ, θ) on the equilibrium outcomes and present the results in the following proposition.

Proposition 7. *Under the combined subsidy scheme (δ, θ), the equilibrium outcomes have the following properties:*

1. *When the effort cost coefficient $\beta \geq \tau$, farmer r's expected income $\tilde{\pi}_r(\delta, \theta)$ is supermodular in (δ, θ). However, when $\beta < \tau$, $\tilde{\pi}_r(\delta, \theta)$ is supermodular in (δ, θ) if and only if $r < \bar{r}$.*

2. *The total farmer income $\tilde{\Pi}(\delta, \theta)$ is supermodular in (δ, θ). Furthermore, suppose that $r_1 > r_2$ and $r_1 > \bar{r}$. Then,*

Table 4. Equilibrium Outcomes for a Given Combined Subsidy (δ, θ)

Farmer r's planting quantity	$\tilde{q}_r(\delta,\theta) = \frac{((a+\theta)\beta+(\alpha-\delta)bM_1(1+\sigma^2))\mu(r)}{\beta(\beta+M_2\cdot b(1+\sigma^2))} - \frac{\alpha-\delta}{\beta}$
Expected total harvest quantity	$E[\tilde{Q}(\delta,\theta)] = \tilde{H}(\delta,\theta) = \frac{(a+\theta)M_2-M_1(\alpha-\delta)}{\beta+M_2\cdot b(1+\sigma^2)}$
Farmer r's expected income	$\tilde{\pi}_r(\delta,\theta) = \frac{\beta\cdot(\tilde{q}_r(\delta,\theta))^2}{2}$

there exists a threshold $\check{\beta}$ such that the income gap, $\tilde{\pi}_{r_1}(\delta,\theta) - \tilde{\pi}_{r_2}(\delta,\theta)$, is supermodular in (δ,θ) if and only if $\beta > \check{\beta}$.

Proposition 7 implies that jointly offering the input and output subsidies under a combined subsidy scheme has a complementary effect on both the income of the farmers with low yield rates (with $r < \bar{r}$) and the total farmer income: after offering one type of subsidy, performance further increases if the government offers the other type of subsidy. Proposition 7 also indicates that when the farmers' effort cost coefficient β is sufficiently large, that complementary effect persists with respect to both the income of the farmers with high yield rates and the income gap.

6.1.2. The Government's Optimal Combined Subsidy. By taking farmer r's best response planting quantity (see Table 4) into consideration, the government decides the optimal subsidies δ^*_m and θ^*_m that maximize the net social welfare $\tilde{\Pi}(\delta,\theta)$ as given in (6) by solving

$$\max_{\delta,\theta} \tilde{W}(\delta,\theta) = \max_{\delta,\theta}\{\tilde{\Pi}(\delta,\theta) + \tilde{U}(\delta,\theta) - \lambda\tilde{G}(\delta,\theta)\}, \tag{19}$$

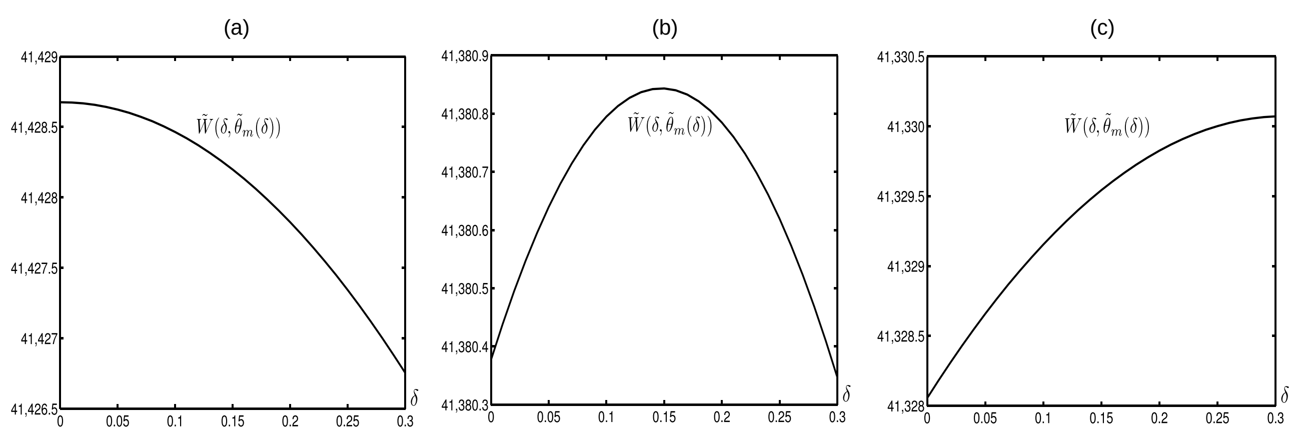
$$s.t. \quad \delta\cdot\tilde{I}(\delta,\theta) + \theta\cdot E[\tilde{Q}(\delta,\theta)] \le \Omega, \tag{20}$$

where (20) is the budget constraint, and the term on the left-hand side, $\delta\cdot\tilde{I}(\delta,\theta) + \theta\cdot E[\tilde{Q}(\delta,\theta)]$, is the expected total subsidy expenditure.

By applying Propositions 1 and 3, we can conclude that the net social welfare $\tilde{W}(\delta,\theta)$ and the expected total subsidy expense $\delta\cdot\tilde{I}(\delta,\theta) + \theta\cdot E[\tilde{Q}(\delta,\theta)]$ both increase in δ and θ. Therefore, the budget constraint must be binding in equilibrium.

Unfortunately, because the Gini coefficient is not well-behaved, the net social welfare function (19) may be convex in θ for a fixed δ. Thus, closed-form expressions for the optimal solution (δ^*_m, θ^*_m) are not tractable. Instead, we must rely on numerical experiments to extract managerial insights. To do so, given the system parameter values,[20] we first fix the input subsidy δ and then numerically determine the corresponding output subsidy $\tilde{\theta}_m(\delta)$ by solving the binding budget constraint. It is worth noting that the baseline input and output subsidy schemes correspond to the two extreme cases of the combined subsidy scheme, $(\delta^*, 0)$ and $(0, \theta^*)$, respectively, where the expressions of δ^* and θ^* are stated in (11) and (16), respectively. Consequently, $\tilde{\theta}_m(0) = \theta^*$ and $\tilde{\theta}_m(\delta^*) = 0$. Furthermore, by substituting $\tilde{\theta}_m(\delta)$ into $\tilde{W}(\delta,\theta)$, we can examine the effect of the input subsidy δ on the net social welfare $\tilde{W}(\delta, \tilde{\theta}_m(\delta))$ as depicted in Figure 4. According to Figure 4(a), the government should adopt the output subsidy scheme by setting $\delta^* = 0$ when the weight λ is sufficiently low. However, as shown in Figure 4(c), the government should adopt the input subsidy scheme by setting $\theta^* = 0$ when the weight λ is sufficiently high. These imply that the results stated in Proposition 6 continue to hold under the combined subsidy scheme. Finally, Figure 4(b) reveals that only when the weight λ takes a moderate value should both input and output subsidies be offered.

Figure 4. Optimal Subsidy Levels Under the Combined Subsidy Scheme



Notes. (a) $\lambda = 200$. (b) $\lambda = 400$. (c) $\lambda = 700$.

6.2. Different Levels of Concern About Farmer Income and Consumer Surplus

Here, we consider the situation in which the government has different levels of concern about the total farmer income and consumer surplus. In this situation, the net social welfare becomes

$$W(\cdot) = \lambda_f \cdot \Pi(\cdot) + \lambda_c \cdot U(\cdot) - \lambda_g \cdot G(\cdot), \tag{21}$$

where λ_f, λ_c, and λ_g are positive and represent different levels of concern about three metrics: the farmers' total income, the consumer surplus, and the aggregate income inequality in terms of the Gini coefficient.[21] Clearly, $W(\cdot)$ reduces to farmer welfare only when $\lambda_c = 0$ and $\lambda_g = 0$.

Because the weights λ_f, λ_c, and λ_g do not affect farmer r's best response planting quantity for any given subsidy, Propositions 1 and 3 continue to hold. However, by noting that these weights do affect the government's subsidy decision via the net social welfare function (21), we obtain the following.

Proposition 8. *When the government has different levels of concern about the total farmer income, consumer surplus, and aggregate income inequality, the optimal subsidy satisfies the following:*

1. *The optimal output subsidy θ^* is always positive, and θ^* solves the binding budget constraint $\theta^* E[\tilde{Q}(\theta^*)] = \Omega$.*
2. *When the budget Ω and the effort cost coefficient β are sufficiently small but the weight assigned to the total farmer income λ_f is sufficiently large, the optimal input subsidy $\delta^* = 0$; when either β is relatively large or λ_f is small, δ^* solves the binding budget constraint $\delta^* \tilde{I}(\delta^*) = \Omega$.*
3. *As long as δ^* solves the binding budget constraint $\delta^* \tilde{I}(\delta^*) = \Omega$, Proposition 5 continues to hold.*

Even when the government expresses different levels of concern over different metrics, the first statement of Proposition 8 implies that offering an output subsidy always improves the net social welfare regardless of the magnitudes of the weight parameters λ_f, λ_c, and λ_g. This result is a natural consequence of Proposition 3.

The second statement of Proposition 8 is more nuanced. First, recall from Proposition 1 that high-yield farmers' income may decrease under the input subsidy scheme δ. Second, it can be easily verified that farmer r's expected income $\tilde{\pi}_r(\delta)$ (see Table 2) is convex in δ so that the total farmer income may first decrease and then increase in δ. Hence, if the weight associated with the total farmer income λ_f is too large and the budget Ω is very small, offering a small input subsidy could hurt the total farmer income. These two observations imply that the government should not offer an input subsidy (i.e., $\delta^* = 0$) when λ_f is too large and Ω is too small.

Combining the first two statements of Proposition 8 indicates that the output subsidy may be more robust over a wider range of concern levels across different metrics than the input subsidy, especially when the government has a tight budget and is primarily concerned about the total farmer income. Finally, the last statement of Proposition 8 implies that, as long as the input subsidy level δ^* solves the binding budget constraint, the results of the comparison of the performances of the two subsidy schemes given in Proposition 5 continue to hold even when the government has different levels of concern about different metrics.

7. Conclusion

Motivated by the mixed empirical evidence on the implications of the two commonly adopted farm subsidy schemes, namely, input and output subsidies, we develop a unified modeling framework to examine and compare the farmer income, consumer surplus, and the aggregate income inequality across farmers with heterogeneous endowed resources (which affect the yield rate) as well as income gap between individual farmers. Although these two subsidies are intended to support farmers, their underlying mechanisms differ subtly: input subsidies are independent of the farmer's yield rate, whereas output subsidies depend on the farmer's yield rate. Because of this subtle difference, we obtain some similar and some different results associated with these two subsidy schemes.

Through adopting the rational expectations equilibrium concept, we analyze the equilibrium outcomes associated with these two subsidy schemes. We find that both schemes can reduce income inequality as measured by the Gini coefficient. However, because of the subtle difference, the two subsidy schemes have different implications. First, whereas the output subsidy scheme is beneficial to all farmers, the input subsidy is beneficial only to low-yield farmers. Second, we find that input subsidies can narrow the income gap between any two individual farmers with different endowed resources, but output subsidies widen this income gap. Consequently, the output subsidy scheme benefits high-yield farmers, whereas the input subsidy scheme benefits low-yield farmers.

We consider the case in which the government has an earmarked budget for providing farmer subsidies as a mechanism to reduce farmer income inequality. Again, because of the subtle difference between the input and output subsidies, these two subsidies have different strengths. A direct comparison of the equilibrium outcomes associated with these two subsidy schemes reveals that input subsidies are more effective than output subsidies in increasing consumer surplus and reducing farmer income inequality in terms of the Gini coefficient. However, output subsidies are more effective than input subsidies in increasing the total farmer income. Therefore, the government's preference for one subsidy scheme over the other depends on its levels of concern about different metrics (total farmer income, consumer surplus, and farmer inequality).

We conclude by discussing the limitations of our model and providing future research directions. As an initial attempt to analyze and compare input and output farm subsidy schemes, our model has several limitations that can be considered as future research directions. First, we assume that the mean yield rate $\mu(r)$ of farmer r is exogenous, which is reasonable over a two- to three-year period. However, because of climate change, this yield rate can change over time, especially when farmers make an effort to improve their yields by using more effective farming techniques or growing different crops. Therefore, it would be interesting to examine the case in which farmers could endogenously determine the yield rate. Second, we assume that the government has complete information about the farmers' cost parameters. However, because of the poor information technology infrastructures in developing countries, the cost parameters may provide imperfect information from the government's perspective. It is of interest for researchers to develop a mechanism that encourages farmers to report their cost information truthfully, thus providing the government with good information when it is choosing a subsidy scheme. Third, we focus on farmer income inequality, which is appropriate for developing countries, such as India, where most people work in the agricultural sector. However, it would be interesting to extend our measure of income inequality to the total national population (including but not exclusive to the agricultural sector). Fourth, although we assume in this study that farmers are risk-neutral, the issue of risk aversion should be explored in a future study.

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Endnotes

[1] See wfp.org/global-hunger-crisis.

[2] The World Food Programme estimates that 82 countries are currently experiencing acute food insecurity. See https://www.wfp.org/emergencies/global-food-crisis.

[3] Gedaref (2017) reports that, in recent years, the harvest costs in Sudan have increased by four times.

[4] In the same spirit, Indian farmers receive rebates from the government on designated seeds purchased at their market prices (Prasad 2016).

[5] Governments in China, Brazil, Thailand, Turkey, and Ukraine also provide farmers with output subsidies intended to help reduce their storage- and transportation-related harvest costs (Organisation for Economic Co-operation and Development 2009, Global Agricultural Information Network 2017).

[6] For example, China's President Xi introduced various economic development programs to reduce rural income inequality (Leng 2021), and India's Prime Minister Modi launched the 2019 "farmers first" campaign to address farmers' income inequality (Bharti and Chancel 2019).

[7] To succinctly develop an aggregate measure of farmer income inequality, we use the Gini coefficient, a common measure of income inequality among specific populations, such as farmers (Giorgi and Gigliarano 2016).

[8] Interested readers are referred to the comprehensive reviews of Rao (1989), Dorward (2009), Sumner et al. (2010), and Jayne and Rashid (2013) and the references therein.

[9] For tractability, the farmers are assumed to be risk neutral. This assumption is commonly adopted in the agricultural operations management literature; see, for example, Tang et al. (2018), Alizamir et al. (2019), and Zegher et al. (2019).

[10] Here, we normalize the mean of the yield uncertainty $E[\varepsilon]$ to be one. Our main results still hold if we relax this normalization.

[11] This demand function is widely adopted in the literature (e.g., Alizamir et al. 2019, Hu et al. 2019) to capture the relationship between market price and output quantity. Additionally, in Online Appendix B, we consider a multiplicative demand function and find that our main results remain intact.

[12] Regarding developing countries, the Nigerian government, for instance, earmarked NGN27 billion for its 2016/2017 agricultural input subsidy program (Michael et al. 2018). Accordingly, we assume that the government subsidy program examined in this paper has a limited annual budget, Ω.

[13] Clearly, when $\lambda = 0$, $W(\cdot)$ degenerates to the traditional measure (i.e., farmer welfare plus the consumer surplus) as examined in the literature (e.g., Liao et al. 2019).

[14] This assumption is reasonable. It is also consistent with the observation that many developing countries have limited financial resources and the budgets of their agricultural programs are always insufficient (Maetz 2013).

[15] The output subsidy θ can be interpreted as a form of price support (e.g., price premium) that is commonly observed. We thank an anonymous referee for pointing out the connection between the output subsidy scheme and the price support scheme.

[16] In contrast, the income gap decreases with the input subsidy δ because all farmers, regardless of whether they are richly or poorly endowed, receive the same per-unit subsidy δ.

[17] The detailed expression of the threshold $\hat{\lambda}$ is provided in (37) in Online Appendix A.

[18] In our paper, the market size is normalized to one; in Alizamir et al. (2019), the number of farmers is 41,190. Therefore, here, b equals its corresponding value times the number of farmers in Alizamir et al. (2019).

[19] We also vary the values of t and α in our numerical studies, and the structural results remain the same.

[20] We use the parameter values associated with Figure 3. We also vary μ_l from 0.5 to 0.75 with a step length of 0.01. All the numerical studies exhibit the same pattern. In Figure 4, $\mu_l = 0.5$, $\Omega = 5{,}000$, and $\sigma^2 = 0.89$.

[21] We thank an anonymous referee for pointing out this scenario.

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