An Economic Analysis of Agricultural Support Prices in Developing Economies

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The goals of the Guaranteed Support Price (GSP) scheme, adopted by several developing countries to support their farmers and the underprivileged population, are threefold: (a) as a supply-side incentive, to ensure high output from the farmers, (b) as a demand-side provisioning tool, to subsidize the consumption needs of the poor, and (c) to maintain an adequate amount of foodgrains as reserve stock, to mitigate the adverse effects of yield uncertainty (food security). We offer analytically-supported insights on the fundamental aspects of this scheme by analyzing a Stackelberg game between a homogenous population of small farmers and a social planner. We model the strategic behavior of the farmers and the consuming population (Above- and Below-Poverty-Line consumers), and compare the equilibrium outcome with that under the Direct Benefits Transfer (DBT) scheme, where the social planner simply distributes the budget among the BPL consumers. The comparison of the social planner's surplus depends on the marginal value from maintaining a reserve stock (i.e., the significance of food security). If this value is high, then the surplus under the GSP scheme strictly dominates that under DBT; otherwise, the surplus is identical. The comparison of the production by the farmers depends on two economic forces – the poorness of the BPL consumers and yield uncertainty. If the poorness is extreme, then the two schemes lead to identical production. If yield uncertainty is dominant, then DBT is ineffective in improving production while the GSP scheme can induce a strictly higher production by strategically choosing the reserve stock.

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1. Introduction

Due to its significant contribution to the gross domestic product and its critical role in shaping the livelihood of a majority of the population, the agricultural sector in many developing economies attracts substantial support from the government. Among the various governmental schemes that support agriculture, *Guaranteed Support Prices* (GSPs; also called *Minimum Support Prices*, or simply, *support prices*) have been adopted by many developing nations, including Bangladesh, Brazil, China, India, Pakistan, Thailand, and Turkey. A guaranteed support price for an agricultural crop is an attractive price at which the government promises to purchase that crop from farmers, regardless of its market price.

Broadly, the goals behind the GSP scheme are threefold:

- As a *supply-side* incentive: An attractive support price for a crop protects the farmers from the adverse effects on its market price due to overproduction and naturally incentivizes them to increase input effort. USDA Foreign Agricultural Service (2014), Directorate of Economics and Statistics (2014)
- As a *demand-side* provisioning tool: The increase in farming effort, engineered via a support price, results in high production, of which the government procures a significant amount and distributes it to the economically weak population at a nominal price. (Parikh and Singh 2007, SMC Investments 2010).
- *Food Security:* Beyond these unexceptionable goals, it is also important for governments in these countries to maintain an adequate amount of foodgrains as *reserve stock* to mitigate the adverse effects due to yield uncertainty. According to Rakshit (2003):

  > "Food security – ironing out large intra- and inter-year variations in food prices through buffer stocking – encompasses a number of goals. One of these goals is of course consumption and price smoothing over a typical crop cycle.".

Typically, support prices are determined on an annual basis. The recommendation for a specific crop primarily depends on its (a) demand and supply, (b) cost of production, and (c) yield uncertainty; see, e.g., Central Statistics Office (2010), Kang (2012). We discuss these factors below.

(a) **Demand-Supply Gap**: Consider a crop that experiences a significantly higher market demand than its supply. The insufficient supply naturally drives the market price high, resulting in the poor finding it difficult to afford the crop at an elevated price. Since the below-poverty-line (BPL) population in developing nations is significant, the government may intervene by offering a support price for this crop to increase its supply and, thereby, its consumption by the population.

(*b*) **Production Cost**: An increase in the cost of farming inputs directly increases the cost of production. One reason for the increase in input costs is the progressive reduction in the average size of a farm. Small farmers are unable to go for mechanization of farming due to physical limitations and, therefore, have to depend on manual labor, which is becoming increasingly scarce and expensive (Kumaraswamy 2012). As production cost increases, it is natural to expect a decrease in the total input effort, resulting in a reduction in the total production and, ultimately, the food-grains available for consumption. Therefore, to elevate the level of input effort by assuring farmers of "good" income that can compensate for the increase in production cost, the government may offer an attractive support price.

(*c*) **Crop-Yield Uncertainty**: Yield uncertainty increases fluctuation in supply (i.e., food-grain production), resulting in unstable market prices and, hence, unstable revenue for farmers. Thus, the government again has an incentive to offer a support price and avoid socially undesirable outcomes by safeguarding farmers from adverse price fluctuations (Gomez-Limon et al. 2002).

Our goal in this paper is to offer analytically-supported insights on several fundamental aspects of the GSP scheme, including its impact on social welfare and total production. Clearly, this analysis should anticipate the operational decisions of the farmers, i.e., their production decisions and their selling decisions to the government and in the open market, in response to a potential support price. Accordingly, we characterize the equilibrium decisions of the farmers enroute to assessing the impact on social welfare. This analysis then allows us to understand how the effectiveness of the GSP scheme, as a supply-side incentive and as a demand-side provisioning tool, is affected by the budget and the characteristics of the population (e.g., the "poorness" of the BPL population), and by yield uncertainty.

In addition to the above factors, our analysis captures other real-world characteristics:

(*d*) **"Small" Farmers**: A majority of farmers in developing countries are small-holders, with each owning or cultivating a small piece of land (on average, less that 2.0 hectares). Accordingly, farmers are assumed to be *price-takers*, i.e., the actions of an individual farmer do not influence the market price.

(*e*) **Multiple Selling Channels for Farmers and a Heterogeneous Consuming Population**: In the presence of the GSP scheme for a crop, a farmer has access to two different outlets to sell his produce: (*i*) selling the crop to the government at the support price, or (*ii*) selling in the open market at the market price. In the open market, we consider two different consumer segments: (*A*) the Above-Poverty-Line or APL consumers, and (*B*) the Below-Poverty-Line or

BPL (or simply "poor") consumers. Our analysis captures both the extent of the "poorness" of the BPL consumers and the relative size of this segment.

(*f*) **Limited Budget of the Government**: The support-price program for a crop – buying the crop from farmers at the GSP and providing it to the BPL population at a nominal price via a country-wide public distribution system (PDS) of ration shops – is financed by a limited budget, which the government determines annually based on the country's economical, demographical, and political environment. In India, for instance, the combined budget for the support-price programs of a total of 26 crops was $16 billion in 2016; this is then partitioned into budgets for individual crops (The Wall Street Journal 2016). Accordingly, our analysis assumes a limited budget for the support-price program of a crop.

1.1. The Direct Benefit Transfer (DBT) Scheme

Besides the GSP scheme, other schemes that directly transfer monetary subsidies, i.e., cash benefits, to the individual beneficiaries (through their bank accounts) have also received increasing patronage in recent years. By Direct Benefit Transfer (DBT) to the bank accounts of the intended beneficiaries, the government is able to increase transparency, eliminate pilferage of funds from intermediaries or middlemen, and streamline existing processes of government delivery across welfare schemes. Consequently, the government is better able to realize *"... simpler and faster flow of information/funds and to ensure accurate targeting of the beneficiaries, de-duplication and reduction of fraud ..."*; see Direct Benefit Transfer (2018). Moreover, the DBT scheme also alleviates costly storage and distribution costs that are associated with the GSP scheme.

In-kind subsidies (e.g., the GSP scheme) have been historically important and continue to remain prevalent in developing economies (Gadenne et al. 2017). Honorati et al. (2015) estimate that 44% of beneficiaries of social safety-net programs around the world receive in-kind transfers. However, an increasing body of research in economics and public policy advocates for cash as the preferred form of subsidy (e.g., the DBT scheme). The proponents of cash transfers argue that they give the poor the flexibility to choose the best opportunities, rather than having the opportunities chosen for them. Blattman et al. (2017) state that "governments in emerging markets have begun to shift from expensive, regressive, and distortionary subsidies of basic commodities such as food or fuels and instead are giving cash to the poor". On the contrary, Gadenne et al. (2017) find that in-kind transfers provide insurance against commodity price risk. This is especially prevalent in developing countries where markets are poorly integrated. Our analysis and subsequent comparison in Section 6 complements Gadenne et al. (2017) in informing this debate about the merits of in-kind subsidies.

1.2. Our Main Contributions

We compare the two schemes – GSP and DBT – along two dimensions: the surplus of the social planner and the total production by the farmers. The comparison of the social planner's surplus between the GSP scheme and the DBT scheme depends on the marginal value from maintaining a reserve stock (i.e., the significance of food security for the social planner). If this marginal value is high, then the social planner's surplus under the GSP scheme *strictly* dominates that under the DBT scheme; otherwise, the surplus under the two schemes is identical. Thus, *the social planner's surplus under the GSP scheme is greater than or equal to that under the DBT scheme.*

The comparison of the total production by the farmers under the two schemes depends on two economic forces – the poorness of the BPL consumers (a demand-side force), and yield uncertainty (a supply-side force) – that act as impediments to high production by the farmers and consumption by the BPL consumers. If the poorness of the BPL consumers is extreme, then the GSP and the DBT scheme lead to an identical production by the farmers, which strictly dominates that under the absence of an intervention. If yield uncertainty is dominant, the DBT scheme is ineffective in improving the production by the farmers. Under the GSP scheme, the social planner can induce a strictly higher production by the farmers by strategically choosing the reserve stock. Thus, *the total production under the GSP scheme is greater than or equal to that under the DBT scheme.*

We also consider a weighted objective of the social planner and demonstrate how different weights on the stakeholder's surplus affect the equilibrium support price and the proportion of inventory withheld. A higher weight on the farmers' surplus (resp., surplus of the BPL consumers) leads to an increase (resp., decrease) in the support price and an increase (resp., decrease) in the withholding proportion.

1.3. Organization of the Paper

The rest of the paper is organized as follows. We review the related literature in Section 2, introduce our model in Section 3, and analyze the market outcome under (a) the absence of any intervention in Section 4, (b) the DBT scheme in Section 5 and (c) the GSP scheme in Section 6. Using numerical experiments, we evaluate the robustness of our results to other two-point distributions in Section 7.2. We also consider a weighted objective of the social planner (where she weighs the surplus of the farmers and the BPL consumers more than that of the APL consumers, the unused budget, and the reserve stock) in Section 7.1. Finally, we conclude in Section 8.

2. Related Literature

While GSPs have been investigated in the agricultural economics literature, a majority of these studies focus on strategic decisions such as the impact of price support on international trade and the number of firms in the industry, and the need for market adjustments due to support prices. Studies that are representative of this line of research include Fox (1956), Dantwala (1967), Spitze (1978), Sjoquist (1979), Gulati and Sharma (1994), Cummings Jr et al. (2006), Josling et al. (2010). In contrast, as discussed above, our aim is to characterize operational decisions of the farmers and the government, and understand the welfare implications of the GSP scheme for the farmers and the consuming population. Besides, we also analyze the DBT scheme and compare the market outcomes under both the GSP and DBT schemes and that under no intervention.

Close to our work, Kazaz et al. (2016) analyze interventions to improve production of artemisenin (used in the malaria-medicine supply chain) under demand and supply uncertainty, and find that support prices lead to greater production by the farmers. However, their setting consists only of the open-market with exogenous demand. In our setting, a budget-constrained social planner announces a support price, procures grains from farmers, and distributes them among the BPL consumers (one segment of the consumer population). Besides, farmers can also sell in the open-market, which is accessible to both APL and BPL consumers. Further, we model the strategic behavior of the APL and BPL consumers and the farmers explicitly.

Motivated by schemes in developed countries, Alizamir et al. (2018) consider two subsidy programs: (a) Price Loss Coverage (PLC) and (b) Agricultural Risk Coverage (ARC). Under PLC, the government offers farmers a subsidy if the market price falls below a reference price, while under ARC, the farmers receive a subsidy if their revenue falls below a threshold. They model competition among a finite population of farmers who sell in the open-market and compare the equilibrium market outcome under both these schemes to that under no intervention. Contrary to conventional wisdom, they find that the producer welfare, consumer welfare, and social welfare, can all be higher under PLC than under ARC. Our setting differs from theirs in many aspects. We consider competition among infinitesimally small farmers who can sell to the social planner as well as in the open-market. The social planner distributes the procured quantity among the BPL consumers, while both the APL and the BPL consumers can access the open market.

Relatedly, Akkaya et al. (2016) study the impact of interventions such as price and cost support under public and private information about government budget on the social welfare. However, in their context, a support price is essentially a price floor that the government announces before the sowing season and pays the farmers the difference between the support price and the open-market price for each unit sold in the open-market. While we consider the interactions among strategic farmers and consumers, in a recent paper, Hu et al. (2019) study the market outcome under a mix of myopic and strategic farmers. They find that a small fraction of strategic farmers can stabilize fluctuating market prices. Chintapalli and Tang (2018) consider farmers' crop-planting decisions when the social planner offers a GSP for two crops. Akin to Akkaya et al. (2016), a support price in their context is "credit-based", i.e., the government does not procure any quantity from the farmers; rather, it pays the farmers the difference between the support and the market price for each unit sold in the market. They find that farmers do not internalize the externality they impose on other farmers in their planting decisions and therefore, vis-a-vis a setting where the social planner chooses the planting decisions, the decentralized planting decisions of the farmers leads to a loss of producer, consumer, and social welfare. It is worth mentioning that both Hu et al. (2019) and Chintapalli and Tang (2018) model the strategic behavior of producers and consumers but do not consider the effect of yield uncertainty.

The GSP scheme is related to a *price-floor*, a concept well-studied in microeconomics; see Varian (1992). In Section 6, we comment on the impact of the GSP scheme and the price floor on the decisions of the different stakeholders as well as on their welfare.

Our work caters to the growing interest in the Operations Management (OM) community on agricultural operations; some recent examples include Huh and Lall (2013) (crop rotation); Dawande et al. (2013) (distribution of surface water between farmers); Chen and Tang (2015), Parker et al. (2016), Tang et al. (2015) (provision of valuable information to farmers); An et al. (2015) (farmer aggregation); Federgruen et al. (2019) (contract farming); Levi et al. (2020) (adulteration in farming supply chains).

A support price is an incentive aimed at improving production. The design of incentives that enable firms to elicit favorable decisions from supply-chain partners is a well-established research area in OM; see, e.g., the survey by Cachon (2003). There is also a growing interest in the OM community in analyzing incentives aimed at improving social welfare and understanding micro-level decisions that consumers make in response to such incentives; some recent examples include Avci et al. (2014), Cohen et al. (2015) (subsidy programs for adoption of electric vehicles and their environmental impact); Mu et al. (2015) (programs to reduce adulteration and improve quality in milk supply chains); Lobel and Perakis (2011) (subsidy programs for adoption of solar panels); Atasu et al. (2009) (programs to promote product recycling); Raz and Ovchinnikov (2015) (government intervention mechanisms for public interest goods).

3. The Model

Consider a social planner (the government), a homogenous farming population of size[1] n that produces a crop, and a consuming population consisting of two segments: (a) the Above-Poverty-Line, or APL consumers of size M, and (b) the Below-Poverty-Line, or BPL (poor) consumers of size kM. The sequence of events is as follows:

[1] Throughout this paper, by size, we refer to the mass of a segment.

Stage 1: Ahead of the sowing season, the social planner, fuelled by a budget B for the GSP scheme, announces the per-unit support price p_g for the crop and a proportion δ_W of the procured crop that is withheld as reserve stock for food security.

Stage 2: Each farmer decides his input effort based on the announced p_g, δ_W, the cost of production, and the distribution of yield uncertainty. Let q_e denote the input effort of a representative farmer. His production cost is modeled as follows: For a fixed q_e, the farmer incurs a production cost of αq_e^2, where α is the production-cost parameter of the farming population. Several papers in the OM literature have modeled farming cost as a quadratic function of the farmer's effort; see, e.g., Alizamir et al. (2018).

Stage 3: The production yield uncertainty is realized: Let γ denote the realized yield. For each farmer, the output corresponding to an input effort of q_e is γq_e.

Stage 4: Each farmer decides the quantities to be sold to the social planner and in the open-market, where the per-unit market price p_m is simultaneously realized. Let q_g (resp., q_m) denote the quantity sold by the farmer to the social planner (resp., in the open-market). The social planner distributes a proportion $(1-\delta_W)$ of the procured crop to the BPL consumers. The BPL consumers have the option of reselling some (or all) of the quantity that they receive from the social planner back into the open market.

The objective of each farmer is to maximize his expected profit while the objective of the social planner is to maximize the expected social welfare. Our main notation is defined in Table 1 in Appendix A. The demand model for the APL and the BPL consumers is presented in Section 3.1 while the supply model of the farmers is presented in Section 3.2. Finally, the social planner's objective is presented in Section 3.3.

3.1. The Demand Model

Recall the two homogenous consumer segments – APL (size M) and BPL (size kM). The maximum consumption of any consumer in either segment is normalized to 1. Thus, the aggregate consumption by the APL consumers (resp., the BPL consumers) is at most M (resp., kM). We present the consumer utility models for APL and BPL consumers below.

APL Consumers Suppose w_{APL} ($>>1$) denotes the wealth of the APL consumers. At a consumption level of ξ, the additional consumption utility to a consumer from the incremental consumption of an infinitesimal quantity $d\xi$ is $(1-\xi)d\xi$. Thus, the marginal consumption utility for a consumer monotonically decreases from 1 (at the minimum consumption level of 0) to 0 (at the maximum consumption level of 1). Corresponding to a consumption quantity $q \in [0,1]$, the net utility derived by an APL consumer is

$$u_{APL}(q) = \underbrace{\int_0^q (1-\xi)d\xi}_{=u_C(q)} + (w_{APL} - p_m q),$$

where $u_C(q) = \int_0^q (1-\xi)d\xi$ is the utility derived from consumption and p_m is the market price. The utility-maximizing quantity consumed by an APL consumer from the open-market at a market price $p_m \in [0,1]$ is

$$q^*_{APL} = \arg\max_{q \geq 0} \; u_{APL}(q) = \arg\max_{q \geq 0} \; \Big[\int_0^q (1-\xi)d\xi + (w_{APL} - p_m q) \Big] \quad (1)$$

$$= (1 - p_m) \quad (2)$$

BPL Consumers The BPL consumers also have access to the open market. The consumption utility model for the BPL consumers is identical to that of the APL consumers', with two differences: (a) these consumers are assumed to be budget-constrained; i.e., they have lower wealth relative to the APL consumers: Let b (<1) denote the wealth of a BPL consumer; and (b) the social planner supplements these consumers with additional quantity for consumption: Let q_S denote the quantity that a BPL consumer receives from the social planner.

We allow for the possibility that the BPL consumers may resell a fraction of the quantity they receive from the social planner back in the open market. Suppose the social planner provides each BPL consumer with a quantity q_S. Then, one of the following outcomes hold:

(a) The market price is smaller than the marginal consumption utility at q_S, i.e., $p_m \leq 1 - q_S$, or

(b) the market price is strictly larger than the marginal consumption utility at q_S, i.e., $p_m > 1 - q_S$.

If the market price is smaller than the marginal consumption utility at q_S (i.e., (a) holds), then the BPL consumers do not find it profitable to sell any quantity they receive from the social planner back into the open-market (rather, they may purchase some quantity from the open-market). On the other hand, if the market-price is strictly higher than the marginal consumption utility at q_S (i.e., (b) holds), then the BPL consumers do not purchase from the open-market; instead, they will find it profitable to sell a fraction of the quantity they receive from the social planner back into the open-market. Combining these two cases, it is straightforward that a BPL consumer either sells in the open-market, or purchases from the open-market, but not both. Let q denote the quantity a BPL consumer consumes from the open market: If the BPL consumer sells in the open-market, then $q \leq 0$; if he purchases from the open market, then $q \geq 0$. The utility-maximizing quantity consumed by a BPL consumer from the open-market at a market price $p_m \in [0,1]$ is

$$q^*_{BPL} = \underset{q \in \left[-q_S, \frac{b}{p_m}\right]}{\arg\max} \; u_{BPL}(q) = \underset{q \in \left[-q_S, \frac{b}{p_m}\right]}{\arg\max} \left[\underbrace{\int_0^{q+q_S} (1-\xi)d\xi}_{=u_C(q+q_S)} + (b - p_m q) \right]. \tag{3}$$

Thus, we have

$$q^*_{BPL} = \min\left\{(1 - q_S - p_m), \frac{b}{p_m}\right\}. \tag{4}$$

Observe that the quantity $(1 - q_S - p_m)$ can be negative, if the market price p_m exceeds $1 - q_S$ (the marginal consumption utility at q_S). Since all BPL consumers are homogeneous, we assume that the social planner supplements each consumer with the same quantity q_S and they consume the same quantity q^*_{BPL} from the open market.

Combining (2) and (4), the aggregate consumer demand at a market price $p_m \in [0,1]$ can be written as:

$$D(p_m) = Mq^*_{APL} + kMq^*_{BPL} = M(1 - p_m) + kM \min\left\{(1 - q_S - p_m), \frac{b}{p_m}\right\}. \tag{5}$$

Alternately, given a certain quantity, say Q, available to be sold in the open-market, the market price p_m is determined by the above equation, i.e., $p_m = D^{-1}(Q)$. We restrict attention to small values of b to reflect the "poorness" of the BPL consumers – we will make this precise in Section 4.

3.2. The Supply Model

We now formulate the decision problems of the farmers. Recall that farmers are assumed to be price-takers, i.e., the actions of an individual farmer do not affect the market outcome in any realistic way. We explicitly model the interactions among strategic farmers. Specifically, farmers face competition from other farmers in their selling decisions in the open-market and to the social planner. Moreover, they anticipate the consequences of their selling decisions to the social planner: First, they anticipate a downward shift in the BPL consumers' demand curves in the open market (that is proportional to the quantity sold by the farmers to the social planner). Second, they anticipate that the BPL consumers may resell some of the quantity they receive from the social planner back in the open-market. Let $\hat{p}_m(\gamma)$ denote the belief that a farmer has about the market price (as a function of the realized yield). The homogeneity of farmers allows us to make two assumptions:

Assumption 3.1. *All farmers hold the same belief $\hat{p}_m(\gamma)$ about the market price, and their production and selling decisions are identical.*

Therefore, we assume that farmers hold rational beliefs, i.e., the actions taken by the farmers given their beliefs lead to an outcome that is consistent with their beliefs. This is a standard assumption in the literature, consistent with the theory of rational expectations. Further, they take identical actions, i.e., they exert an effort q_e, and sell q_m (resp., q_g) in the open-market (resp., to the social planner).[2]

Consider a representative farmer, who obtains revenue from two sources:

(*a*) by selling to the social planner, and

(*b*) by selling in the open market.

For any support price $p_g \geq 0$ chosen by the social planner, the farmer's belief $\hat{p}_m(\gamma)$ about the market price, the effort q_e chosen by the farmer in the second stage, and the yield γ chosen by nature in the third-stage, the fourth-stage optimization problem is as follows: The farmer decides q_m and q_g, the quantity of produce sold in the open market and to the social planner, respectively. Since costs are sunk in the second stage, it suffices to maximize his revenues in the fourth stage. That is,

$$\left.\begin{aligned} & r^\gamma(q_e) = \max_{q_m, q_g} \quad [\hat{p}_m(\gamma) q_m + p_g q_g] \\ & \text{subject to:} \\ & \qquad q_m + q_g \leq \gamma q_e, \\ & \qquad p_g q_g \leq \tfrac{B}{n}, \\ & \qquad (q_m, q_g) \geq 0. \end{aligned}\right\} \quad \text{Problem } \mathsf{P}_\mathsf{f}^2$$

Denote the optimal values of q_m (resp., q_g) obtained from Problem P_f^2 by q_m^* (resp., q_g^*). Indeed, q_m^* and q_g^* depend on the realized yield γ; for notational simplicity, we avoid stating this dependence explicitly. The second constraint, $p_g q_g \leq \frac{B}{n}$ (in the set of constraints above) pertains to the maximum quantity that the social planner procures from an individual farmer – we assume that the social planner rations his budget equally among the farmers. We then write the second-stage optimization problem as follows:

$$\left.\max_{q_e \geq 0} \; \pi_f(q_e) = -\alpha q_e^2 + \mathbb{E}_\gamma [r^\gamma(q_e)]. \quad \right\} \quad \text{Problem } \mathsf{P}_\mathsf{f}^1$$

Let q_e^* denote the optimal value of q_e obtained from Problem P_f^1.

[2] An alternative is to consider asymmetric pure strategies, where each farmer either sells to the social planner or in the open market. In such a case, while the equilibrium effort of all the farmers is identical, we solve for the proportion of farmers that sell in the open market and to the social planner. It can be easily seen that this does not alter the quantity procured by the social planner and made available in the open market. Consequently, the market price, and therefore, the market outcome, are identical.

3.3. Objective of the Social Planner

The objective function Π_S of the social planner is the sum total of the surplus derived by each segment of the population, and consists of the following components:

(a) The consumer surplus derived by the APL and the BPL consumers, $Mu_{APL} + kMu_{BPL}$,
(b) The producer surplus derived by the farmers, $n\pi_f$,
(c) The unused budget of the social planner, $B - np_g q_g$,
(d) The value from withheld inventory, $\eta\,(nq_g\delta_W)$, where η denotes the social planner's (constant) marginal utility from maintaining a reserve stock.

Thus, the social planner's problem is as follows:[3]

$$\max_{p_g \geq 0, \delta_W \in [0,1]} \Pi_S = \mathbb{E}_\gamma \left[Mu_{APL} + kMu_{BPL} + n\pi_f + (B - np_g q_g) + \eta\,(nq_g\delta_W) \right]. \tag{6}$$

Observe from (1) and (3) that the terms w_{APL} and b constitute transfers from the consumers to the farmers. Substituting for the equilibrium consumption quantities of the APL and BPL consumers from (2) and (4) in (6), the social planner's surplus can be written as:

$$\begin{aligned}\Pi_S = {} & (Mw_{APL} + kMb + B) + \\ & \mathbb{E}_\gamma \left[M \int_0^{q^*_{APL}} (1 - p_m(\gamma) - \xi)\, d\xi + kM \left(\int_0^{q_S + q^*_{BPL}} (1 - \xi)\, d\xi - p_m(\gamma) q^*_{BPL} \right) - np_g q_g + \eta\,(nq_g\delta_W) \right] + \\ & n\pi_f(q^*_e)\end{aligned}$$

The first term is the total wealth across all the stakeholders, and is a constant. Therefore, it is sufficient to consider the remaining terms in the social planner's objective. Further, all monetary payments consist of transfers from one agent to another. Therefore, we can rewrite the social planner's surplus as follows:

$$\begin{aligned}\Pi_S = {} & (Mw_{APL} + kMb + B) + \\ & \underbrace{\mathbb{E}_\gamma \left[\underbrace{M \int_0^{q^*_{APL}} (1 - \xi) d\xi + kM \int_0^{q_S + q^*_{BPL}} (1 - \xi) d\xi +}_{\text{Consumption Utility}} \underbrace{\eta\,(nq_g\delta_W)}_{\text{Value from Withheld Inventory}} \right] - \underbrace{n\alpha {q^*_e}^2}_{\text{Production Cost}}}_{=\hat{\Pi}_S}\end{aligned} \tag{7}$$

To understand the role of a scheme like the GSP, we first study the market outcome in the absence of any intervention (i.e., the "free-market" outcome). We then demonstrate the reasons that motivate the need for a market intervention.

[3] For ease of notation, we suppress the dependencies of the surplus on the equilibrium decisions that arise as a result of the social planner's decision.

Remark 3.1. **(Connection to Price Floors)** A price floor for a good is an intervention through which the government imposes a lower bound on its market price. For it to be effective, a price floor should clearly be higher than the free-market equilibrium price. From standard microeconomic theory we know that, under such a price floor, the equilibrium production is higher while the demand is lower, relative to the case where the price floor is absent. Consequently, compared to the outcome in a free market, the consumer surplus is lower, the producer surplus is higher, and the total social welfare is lower; the loss in social welfare from a price floor is referred to as the "dead-weight" loss; see, e.g., Varian (1992).

Unlike in a price floor, the government does not regulate the market price directly under the GSP scheme. Indeed, there are two outlets for the producers to sell under a GSP scheme: the open market and the government. The government offers a fixed support price, while the open market price is determined by supply and demand. On their part, the producers (farmers) can sell partial amounts in both these outlets, in equilibrium. The other important change in the action of a GSP scheme comes from the structure of the demand side: The consuming population consists of two segments, namely the BPL and APL consumers. The amount procured by the government under the scheme is used to increase the consumption of only one of these two segments (the BPL consumers). As far as the operational decisions are concerned, the presence of two consumer segments and two selling markets for the producers – of which one (the open market) is accessible to both consumer segments and the other (the government) is accessible only to one segment (the BPL consumers) – makes the equilibrium analysis of the producers' selling decisions and the social planner's choice of the support price quite challenging. ■

4. Absence of an Intervention: The Laissez-Faire Outcome

In the absence of any market intervention (henceforth "No Intervention", or NI), the farmers sell their entire produce in the open market. Each farmer decides his (expected) profit-maximizing effort q_e, given his belief about the market price $\hat{p}_m(\gamma)$, by solving the following problem:

$$\max_{q_e \geq 0} \pi_f(q_e) = \mathbb{E}[\hat{p}_m(\gamma) q_e \gamma] - \alpha q_e^2, \tag{8}$$

where the term inside the expectation is the farmer's belief about his revenue when the realized yield is γ. The farmer's profit maximizing effort q_e^*, given his belief $\hat{p}_m(\gamma)$, is

$$q_e^* = \frac{\mathbb{E}[\hat{p}_m(\gamma)\gamma]}{2\alpha}. \tag{9}$$

Let $\mathcal{Q}$ denote the total production by the farmers; $\mathcal{Q} = nq_e^* = n\left(\frac{\mathbb{E}[\hat{p}_m(\gamma)\gamma]}{2\alpha}\right)$. From (9), farmers exert greater effort if they believe that the market price is higher. Notice that the largest value of $\mathcal{Q}$

is $\frac{n}{2\alpha}$ (which occurs if γ is deterministically equal to 1 and $\hat{p}_m(1)=1$). Recall that the maximum consumption by any consumer is capped at 1. To avoid settings that result in excess supply, we make the following assumption.

Assumption 4.1. **(Large Consumer Population)** *The maximum production from the farmers does not exceed the maximum consumption by the consumers, i.e.,* $\frac{n}{2\alpha} < M(1+k)$.

This is a reasonable assumption, since many developing countries have a large consumer population.

When the realized yield is γ, the total quantity available to be sold in the open market is $\mathcal{Q}\gamma$. In the absence of any scheme, the BPL consumers do not receive any support from the social planner, i.e., $q_S=0$. The market price $p_m(\gamma)$ is obtained from the following:

$$D(p_m(\gamma)) = \mathcal{Q}\gamma, \text{ and} \tag{10}$$

$$\hat{p}_m(\gamma) = p_m(\gamma) \tag{11}$$

(10) states that, at the prevailing market-price, the total demand from the consuming population is equal to the total production from the farmers (i.e., the market clears). (11) states that farmers' belief is consistent with the outcome (i.e., farmers hold rational beliefs). Using these two conditions, we can obtain the equilibrium of the game, i.e., the equilibrium effort of the farmers and the equilibrium market price (consistent with the farmers' belief) for any realized yield γ.

Two factors play a key role in determining the equilibrium effort of the farmers – yield uncertainty, as a supply-side impediment, and the "poorness" of the BPL consumers, as a demand-side impediment. In what follows, we isolate the role of each of these factors by solving the equilibrium of this game in two special cases. We then explain the significance of the two results below (namely, Lemmas 4.1 and 4.2) that motivate the need for an intervention.

4.1. Effect of Yield Uncertainty

To isolate the effect of yield uncertainty on the equilibrium outcome, suppose that the wealth b of a BPL consumer is sufficiently high – in this case, the BPL consumers are effectively not budget-constrained.[4] Therefore, from (4), we have $q^*_{BPL}=1-p_m$. Let $\mu=\mathbb{E}[\gamma]$ and $\sigma^2=\mathrm{Var}(\gamma)$. The following result states the equilibrium outcome under this special case.

Lemma 4.1. *In the absence of any intervention, if* $b\geq\frac{1}{4}$, *the equilibrium effort of a farmer is*

$$q_e^{*\mathsf{NI}} = \frac{\mu}{2\alpha}\Big(\frac{M(1+k)}{M(1+k)+\frac{n}{2\alpha}(\mu^2+\sigma^2)}\Big) \tag{12}$$

and the equilibrium market price when the realized yield is γ *is*

$$p_m(\gamma)^{\mathsf{NI}} = 1-\gamma\Big(\frac{\frac{n}{2\alpha}\mu}{M(1+k)+\frac{n}{2\alpha}(\mu^2+\sigma^2)}\Big). \tag{13}$$

[4] A sufficient condition under which this occurs is $b\geq\frac{1}{4}$; under this condition, we have $\frac{b}{p_m}\geq(1-p_m)$, since $p_m\in[0,1]$.

When the BPL consumers have sufficient wealth, the only impediment to high production by the farmers is the uncertainty in yield. All else equal, the equilibrium effort of a farmer q_e^* increases in the mean μ and decreases in the variance σ^2. Consequently, as yield becomes more variable, the equilibrium production effort by the farmers decreases – this argues for an incentive to improve production under yield uncertainty.

4.2. Effect of "Poorness" of the BPL Consumers

To better understand the effect of limited wealth of the BPL consumers and in the rest of the paper, we consider a two-point distribution for the yield. Suppose that

$$\gamma = \begin{cases} 1, \text{ w.p. } \theta; \\ 0, \text{ w.p. } (1-\theta). \end{cases}$$

We define a threshold level of the budget, denoted by $b^*(\theta)$, as follows:

$$b^*(\theta) = \frac{M(1+k)\frac{n\theta}{2\alpha}}{\left(M(1+k)+\frac{n\theta}{2\alpha}\right)^2}. \tag{14}$$

Observe that $b^*(\theta)$ is a strictly increasing function of θ, $b^*(0)=0$ and $b^*(1)<\frac{1}{4}$, since $\frac{n}{2\alpha}<M(1+k)$. Intuitively, for a fixed $\theta\in[0,1]$, $b^*(\theta)$ denotes the maximum value of b for a BPL consumer to be deemed as "budget-constrained". In other words, if $b\geq b^*(\theta)$, then the BPL consumers are effectively not budget-constrained; therefore, at his equilibrium consumption q_{BPL}^*, a BPL consumer's marginal consumption utility equals the market price p_m.

From (9), we have that $q_e^*=\frac{\theta\hat{p}_m(1)}{2\alpha}$. The following result states the equilibrium outcome under this setting.

LEMMA 4.2. *Consider a fixed value of $\theta\in[0,1]$. In the absence of any intervention, the equilibrium effort and the market price are as follows:*

1. *If $b<b^*(\theta)$, then*

$$q_e^{*\mathsf{NI}} = \frac{\theta}{2\alpha}\left(\frac{M+\sqrt{M^2+4kMb(M+\frac{n\theta}{2\alpha})}}{2(M+\frac{n\theta}{2\alpha})}\right),$$

and the equilibrium market price (under the high yield realization) is

$$p_m(1)^{\mathsf{NI}} = \frac{M+\sqrt{M^2+4kMb(M+\frac{n\theta}{2\alpha})}}{2(M+\frac{n\theta}{2\alpha})}. \tag{15}$$

2. *If $b\geq b^*(\theta)$, then*

$$q_e^{*\mathsf{NI}} = \frac{\theta}{2\alpha}\left(\frac{M(1+k)}{M(1+k)+\frac{n\theta}{2\alpha}}\right),$$

and the equilibrium market price (under the high yield realization) is

$$p_m(1)^{\mathsf{NI}} = \frac{M(1+k)}{M(1+k)+\frac{n\theta}{2\alpha}}. \tag{16}$$

Combining (15) and (16), we can succinctly state the outcome under NI as $\mathcal{Q}^{\mathsf{NI}} = n\frac{\theta p_m(1)^{\mathsf{NI}}}{2\alpha}$ where

$$p_m(1)^{\mathsf{NI}} = \min\left\{\frac{M + \sqrt{M^2 + 4kMb(M + \frac{n\theta}{2\alpha})}}{2(M + \frac{n\theta}{2\alpha})}, \frac{M(1+k)}{M(1+k) + \frac{n\theta}{2\alpha}}\right\}. \tag{17}$$

Lemma 4.2 is interesting for several reasons:

(a) **BPL Consumers' Poverty as a Demand-Side Impediment to Production:** Suppose that $b < b^*(\theta)$: In this case, the BPL consumers are "budget-contrained". Precisely, the marginal utility from consumption (for a BPL consumer) is strictly higher than the market price, i.e., $1 - \frac{b}{p_m(1)} > p_m(1)$. Stated differently, if the BPL consumers had more wealth, they would *choose* to purchase more from the open market at the prevailing market price. Farmers rationally anticipate the low buying power of the BPL consumers and therefore their equilibrium production effort is lower. At low values of b, the production by the farmers and the consumption by the BPL consumers is low, which justifies the need for an intervention by the social planner, both as a supply-side and a demand-side stimulant. As b increases, the buying power of the BPL consumers also increases. Consequently, the equilibrium production effort by the farmers also increases, i.e., q_e^* is increasing in b. Beyond $b^*(\theta)$, yield uncertainty plays a dominant role. As a result, beyond $b^*(\theta)$, the equilibrium effort q_e^* is a constant.

(b) **BPL Consumers' Poverty vis-à-vis Yield Uncertainty as Impediments to Production:** Consider a fixed $b \in [0, b^*(1)]$ and let $\theta^* = {b^*}^{-1}(b)$: The result states that BPL consumers are "budget-constrained" only when $\theta > \theta^*$. A consequence of this result is that if a high yield realization is less likely to occur (i.e., $\theta < \theta^*$), an increase in the wealth of the BPL consumers has no effect on the equilibrium outcome.

(c) **BPL Consumers' Poverty as an Externality to the APL Consumers' Consumption:** Consider a fixed value of θ and suppose that $b < b^*(\theta)$: A decrease in b leads to a decrease in the equilibrium effort q_e^* and a decrease in the market price $p_m(1)$. Consequently, the quantity consumed by an APL consumer, $1 - p_m(1)$, increases. In other words, as BPL consumers become poorer, the total production effort by the farmers decreases but the equilibrium consumption of the APL consumers increases.

To summarize, Lemmas 4.1 and 4.2 justify the need for an intervention in light of the yield uncertainty and the limited wealth of the poor consumers. In what follows, we analyze the Direct Benefit Transfer mechanism (DBT) as a benchmark intervention and then proceed with the analysis of the Guaranteed Support Price (GSP) scheme.

5. Benchmark Intervention: The Direct Benefit Transfer Scheme[5]

Consider the social planner fueled by a budget $B(>0)$. Let $\beta = \frac{B}{kM}$. Under the DBT scheme, the social planner augments each BPL consumer's wealth using his budget – therefore, the wealth of each BPL consumer becomes $b+\beta$.[6] As is the case in developing countries, we assume that the budget for the DBT scheme is limited – consequently, β is small relative to b. Specifically, we make the following assumption:

Assumption 5.1. **(Limited Budget)** *The budget B of the social planner is less than the total value of trade that occurs in the open-market under NI. That is,*

$$B < \underbrace{p_m(1)^{\mathsf{NI}}\,\mathcal{Q}^{\mathsf{NI}}}_{\textit{market price}\,\times\,\textit{quantity of foodgrains}} \tag{18}$$

$$\textit{Using (17), we have:}\quad B < n\frac{\theta}{2\alpha}\left(\min\left\{\frac{M+\sqrt{M^2+4kMb(M+\frac{n\theta}{2\alpha})}}{2(M+\frac{n\theta}{2\alpha})}, \frac{M(1+k)}{M(1+k)+\frac{n\theta}{2\alpha}}\right\}\right)^2$$

From (15) and (16), $p_m(1)^{\mathsf{NI}}\,\mathcal{Q}^{\mathsf{NI}}$ (the RHS of (18)) is increasing in θ. Therefore, (18) can be equivalently stated as $\theta > \underline{\theta}$ for some $\underline{\theta} \in (0,1)$, i.e., the yield uncertainty is not acute.

Recall the definition of $b^*(\theta)$ from (14). For a fixed θ, one of the following occurs:

(a) $b < b+\beta < b^*(\theta)$,

(b) $b \le b^*(\theta) \le b+\beta$, and

(c) $b^*(\theta) < b < b+\beta$.

Since β is small relative to b, we ignore case (b) and focus on cases (a) and (c). Recall, from Lemma 4.2, that under NI, the effect of an increase in the wealth of the BPL consumers on the market outcome depends on the relative comparison between b and $b^*(\theta)$. Therefore, we analyze cases (a) and (c) separately.

5.1. Case (a): $b+\beta < b^*(\theta)$ (Poorness is Extreme)

Recall that under NI, this setting corresponds to the case where the "poorness" of the BPL consumers plays a role in determining the equilibrium effort of the farmers (case 1 in Lemma 4.2).

[5] We thank an anonymous reviewer for suggesting this comparison.

[6] An alternate cash transfer scheme is one where the social planner distributes his budget among the farmers, instead of the BPL consumers, as considered in this section. However, it should be obvious to the reader that, relative to NI, such a scheme does not alter incentives of any player. Therefore, the market outcome under such a scheme is identical to NI, except that the utility of each farmer increases by an amount equal to the wealth he receives from the social planner, i.e., $\frac{B}{n}$ (under NI, the budget was left unused by the social planner). Consequently, the social planner's surplus is also identical to that under NI. Further, in Section 6, we show that this alternate scheme can be theoretically implemented by the GSP scheme as a special case.

Further, an increase in the BPL consumers' wealth results in an increase in the equilibrium production effort by the farmers (i.e., q_e^* is increasing in b). Therefore, it is straightforward to see that the DBT scheme – through which the social planner provides additional wealth to the BPL consumers – results in an increase in the production effort of the farmers.

Theorem 5.1 below compares the equilibrium outcomes and the social planner's surplus under DBT and NI. Under NI, the social planner's budget ($= kM\beta$) is left unused. Under DBT, the BPL consumers strictly prefer to purchase more from the open-market using the additional wealth β (instead of keeping it unused). Therefore, the surplus of the BPL consumers under the DBT scheme exceeds the sum of their surplus under NI and the additional wealth β, i.e., ${u_{BPL}}^{\mathsf{DBT}} > {u_{BPL}}^{\mathsf{NI}} + \beta$. Relative to NI, the equilibrium effort of the farmers and the market-price are higher under DBT. Although their production costs are higher, the expected profit of the farmers increases due to higher revenues. However, the higher market-price results in the APL consumers being worse-off. Nevertheless, the total increase in the surplus of the BPL consumers and the farmers offsets the decrease in the surplus of the APL consumers and the unused budget; thus, the surplus of the social planner under the DBT scheme is strictly higher than that under NI.

THEOREM 5.1. *If $b+\beta < b^*(\theta)$, then the farmers' equilibrium effort under the* DBT *scheme is*

$$q_e^{*\mathsf{DBT}} = \frac{\theta}{2\alpha}\left(\frac{M+\sqrt{M^2+4kM(b+\beta)(M+\frac{n\theta}{2\alpha})}}{2(M+\frac{n\theta}{2\alpha})}\right),$$

and the equilibrium market price (under the high-yield realization) is

$$p_m(1)^{\mathsf{DBT}} = \frac{M+\sqrt{M^2+4kM(b+\beta)(M+\frac{n\theta}{2\alpha})}}{2(M+\frac{n\theta}{2\alpha})}. \tag{19}$$

Thus, relative to NI*, the total production by the farmers and the market price (under the high-yield realization) are higher under the* DBT *scheme, i.e., $\mathcal{Q}^{\mathsf{DBT}} > \mathcal{Q}^{\mathsf{NI}}$ and $p_m(1)^{\mathsf{DBT}} > p_m(1)^{\mathsf{NI}}$. Further, the surplus of the social planner is strictly higher under the* DBT *scheme, i.e., $\Pi_S^{\mathsf{DBT}} > \Pi_S^{\mathsf{NI}}$.*

5.2. Case (c): $b > b^*(\theta)$ (Yield Uncertainty is Dominant)

Under NI, this setting corresponds to the case where yield uncertainty is dominant in the determination of the equilibrium effort of the farmers and the BPL consumers are effectively not budget-constrained (case 2 in Lemma 4.2). Recall that, in this case, an increase in the BPL consumers' wealth has no effect on the market outcome. The additional wealth of the BPL consumers does not alter the incentives of the farmers to increase their production. Therefore, relative to NI, the DBT scheme does not alter the market outcome, i.e., there is no improvement in the production effort of the farmers or the social planner's surplus. The following result states this finding; the proof follows from Lemma 4.2.

Theorem 5.2. *If $b > b^*(\theta)$, then the farmers' equilibrium effort under the* DBT *scheme and the market price under the high-yield realization are identical to the respective outcomes under* NI. *That is,*

$$q_e^{*\mathsf{DBT}}(=q_e^{*\mathsf{NI}}) = \frac{\theta}{2\alpha}\left(\frac{M(1+k)}{M(1+k)+\frac{n\theta}{2\alpha}}\right) \text{ and } p_m(1)^{\mathsf{DBT}}(=p_m(1)^{\mathsf{NI}}) = \frac{M(1+k)}{M(1+k)+\frac{n\theta}{2\alpha}} \qquad (20)$$

Consequently, the total production by the farmers and the social planner's surplus under the DBT *scheme is identical to that under* NI, *i.e.,* $\mathcal{Q}^{\mathsf{DBT}} = \mathcal{Q}^{\mathsf{NI}}$ *and* $\Pi_S^{\mathsf{DBT}} = \Pi_S^{\mathsf{NI}}$.

In summary, relative to NI, the DBT scheme leads to a strict improvement in the production effort of the farmers and the social planner's surplus if the poorness of the BPL consumers and yield uncertainty both play a role in determining the equilibrium effort of the farmers and the market price. However, if the poorness of the BPL consumers does not play a role (i.e., only yield uncertainty is a factor), then the DBT scheme is ineffective in improving the market outcome. Next, we study how the GSP scheme affects the market outcome in both these cases. We then contrast the outcome under the GSP scheme with that under the DBT scheme and under NI.

6. The Guaranteed Support Price Scheme: Analysis

We analyze the market outcome under the GSP scheme for any announced support price, p_g, and for any proportion, δ_W, of the procured crop withheld as reserve stock (i.e., both on- and off-equilibrium values of (p_g, δ_W)). We then use these results to identify the equilibrium (p_g, δ_W). Finally, we compare the social planner's surplus under the GSP and DBT schemes.

Recall the sequence of events under the GSP scheme: The social planner announces the support price p_g and the proportion withheld δ_W ahead of the sowing season. The farmers form rational beliefs about the market price: let $\hat{p}_m(1)$ (resp., $\hat{p}_m(0)$) denote the belief about the market price under the high-yield (resp., low-yield) realization. Nature chooses the realized yield γ, and the farmers make their selling decisions (q_g, q_m). The realized open-market price is consistent with the farmers' beliefs. It is straightforward that $\hat{p}_m(0) = 1$ and $\hat{p}_m(1) \leq 1$. For any choice (p_g, δ_W) of the social planner, one of the following occurs:

(i) $p_g < \hat{p}_m(1)$: The farmers do not sell to the social planner and sell their entire output in the open-market.

(ii) $p_g > \hat{p}_m(1)$: The farmers sell the maximum possible quantity to the social planner, and then sell any remaining quantity in the open market.

(iii) $p_g = \hat{p}_m(1)$: The farmers are indifferent between selling to the social planner and in the open-market.

In the result below, we solve for the farmer's effort and the selling decisions given his belief about the market price and the announced support price.[7]

LEMMA 6.1. *For any announced (p_g, δ_W) and beliefs $(\hat{p}_m(0), \hat{p}_m(1))$, the farmer's equilibrium effort (solution to Problem P_f^1) and his selling decisions (solution to Problem P_f^2) are as follows:*

(i) If $p_g < \hat{p}_m(1)$, then $q_e^* = \frac{\theta}{2\alpha}\hat{p}_m(1)$, $q_g = 0$, and $q_m = q_e$.

(ii) If $p_g = \hat{p}_m(1)$, then $q_e^* = \frac{\theta}{2\alpha}p_g$ and any choice of (q_g, q_m) such that $q_g, q_m \geq 0$ and $q_g + q_m = q_e$ is an equilibrium.

(iii) If $p_g > \hat{p}_m(1)$, then

$$q_e^* = \begin{cases} \frac{\theta}{2\alpha}p_g, & \frac{\theta}{2\alpha}\hat{p}_m(1) \leq \frac{\theta}{2\alpha}p_g \leq \frac{B}{np_g}; \\ \frac{B}{np_g}, & \frac{\theta}{2\alpha}\hat{p}_m(1) \leq \frac{B}{np_g} \leq \frac{\theta}{2\alpha}p_g; \\ \frac{\theta}{2\alpha}\hat{p}_m(1), & \frac{B}{np_g} \leq \frac{\theta}{2\alpha}\hat{p}_m(1) \leq \frac{\theta}{2\alpha}p_g. \end{cases}$$

$q_g = \min\left\{q_e, \frac{B}{np_g}\right\}$, *and* $q_m = q_e - q_g = \max\{0, q_e - \frac{B}{np_g}\}$.

6.1. Case (a): $b + \beta < b^*(\theta)$ (Poorness is Extreme)

In the result below, we obtain the market outcome corresponding to any (p_g, δ_W) announced by the social planner. Subsequently, we use these results to determine the equilibrium decisions of the social planner.

LEMMA 6.2. ***(Production and Selling Decisions)*** *If $b + \beta < b^*(\theta)$, then for any (p_g, δ_W), the market outcome in the corresponding subgame is as follows:*

$$q_e = \frac{\theta}{2\alpha}p_m(1), \quad q_g = \begin{cases} 0, & p_g < p_m(1)^{\mathsf{NI}}; \\ \frac{\theta}{2\alpha}p_g - \frac{1}{n}\left(M(1-p_g) + kM\frac{b}{p_g}\right), & p_g \in [p_m(1)^{\mathsf{NI}}, p_m(1)^{\mathsf{DBT}}]; \\ \frac{B}{np_g}, & p_g > p_m(1)^{\mathsf{DBT}}. \end{cases}$$

$$\text{where } p_m(1) = \begin{cases} p_m(1)^{\mathsf{NI}}, & \text{if } p_g < p_m(1)^{\mathsf{NI}}; \\ p_g, & \text{if } p_g \in [p_m(1)^{\mathsf{NI}}, p_m(1)^{\mathsf{DBT}}]; \\ \frac{\left(M+\frac{B}{p_g}\right)+\sqrt{\left(M+\frac{B}{p_g}\right)^2+4bkM\left(M+\frac{n\theta}{2\alpha}\right)}}{2\left(M+\frac{n\theta}{2\alpha}\right)}, & \text{if } p_g > p_m(1)^{\mathsf{DBT}}. \end{cases}$$

In particular, $p_m(1)$ is independent of δ_W.

We now proceed to identify the equilibrium (p_g, δ_W). Recall, from Section 3.3, that η denotes the social planner's marginal value from maintaining a reserve stock. For a fixed p_g, define the following:

$$\underline{\eta}(p_g) = 1 - \left(\frac{b}{p_g} + \frac{n}{kM}q_g\right), \text{ and } \overline{\eta}(p_g) = 1 - \frac{b}{p_g}, \tag{21}$$

where q_g is as shown in Lemma 6.2.

[7] As remarked in Section 3.2, an alternative is to consider asymmetric pure strategies, where we solve for the proportion of farmers who sell in the open market and to the social planner – such a consideration leads to an identical market outcome.

THEOREM 6.1. ***(Equilibrium Support Price and Proportion Withheld)*** *The equilibrium decisions of the social planner are as follows:*

$$p_g = p_m(1)^{\mathsf{DBT}}, \quad \delta_W = \begin{cases} 0, & \text{if } \eta < \underline{\eta}(p_m(1)^{\mathsf{DBT}}); \\ \left(\frac{\eta - \underline{\eta}\left(p_m(1)^{\mathsf{DBT}}\right)}{\frac{\beta}{p_m(1)^{\mathsf{DBT}}}}\right), & \text{if } \eta \in \left[\underline{\eta}(p_m(1)^{\mathsf{DBT}}), \overline{\eta}(p_m(1)^{\mathsf{DBT}})\right]; \\ 1, & \text{if } \eta > \overline{\eta}(p_m(1)^{\mathsf{DBT}}). \end{cases}$$

Since $b < b^*(\theta)$ (i.e., poorness is dominant), withholding by the social planner does not affect the market price because the demand curve of the BPL consumers does not shift upwards. Therefore, the market-price remains independent of δ_W, and hence the equilibrium support price is $p_g = p_m(1)^{\mathsf{DBT}}$. While withholding by the social planner leads to lower consumption by the BPL consumers, the loss in the BPL consumer surplus is offset by the value from withheld inventory if η is high. Therefore, the social planner's equilibrium withholding is zero if $\eta < \underline{\eta}(p_m(1)^{\mathsf{DBT}})$, but is positive and increasing in η beyond $\underline{\eta}(p_m(1)^{\mathsf{DBT}})$.

6.2. Case (c): $b > b^*(\theta)$ (Yield Uncertainty is Dominant)

Recall from Section 5.2 that if $b > b^*(\theta)$, then the DBT scheme is ineffective in improving the market outcome relative to NI. Specifically, the production effort of the farmers, the market price, and the social planner's surplus under the DBT scheme are all identical to those under NI. Further, recall the expression for $p_m(1)^{\mathsf{NI}}$ $(= p_m(1)^{\mathsf{DBT}})$ from (16).

Lemma 6.3 below identifies the market outcome under any announced support price p_g and proportion withheld δ_W. This result helps us in obtaining the equilibrium decisions of the social planner (Theorem 6.2). For convenience, define $\breve{p}_g(\delta_W)$ as follows:

$$\breve{p}_g(\delta_W) = p_m(1)^{\mathsf{NI}} \left(\frac{1}{2} + \sqrt{\frac{1}{4} + \frac{B\delta_W}{M(1+k)p_m(1)^{\mathsf{NI}}}} \right). \tag{22}$$

It is straightforward that $\breve{p}_g(\delta_W)$ is strictly increasing in δ_W and $\breve{p}_g(0) = p_m(1)^{\mathsf{NI}}$.

LEMMA 6.3. ***(Production and Selling Decisions)*** *If $b > b^*(\theta)$ and Assumption 5.1 holds, then for any (p_g, δ_W), the market outcome in the corresponding subgame is as follows:*

$$q_e = \frac{\theta}{2\alpha} p_m(1), \quad q_g = \begin{cases} 0, & \text{if } p_g < p_m(1)^{\mathsf{NI}}; \\ \frac{\theta}{2\alpha} p_g - \frac{M(1+k)}{n}(1 - p_g), & \text{if } p_g \in [p_m(1)^{\mathsf{NI}}, \breve{p}_g(\delta_W)]; \\ \frac{B}{np_g}, & \text{if } p_g > \breve{p}_g(\delta_W). \end{cases}$$

$$\text{where } p_m(1) = \begin{cases} p_m(1)^{\mathsf{NI}}, & \text{if } p_g < p_m(1)^{\mathsf{NI}}; \\ p_g, & \text{if } p_g \in [p_m(1)^{\mathsf{NI}}, \breve{p}_g(\delta_W)]; \\ p_m(1)^{\mathsf{NI}} + \frac{\frac{B}{p_g}}{M(1+k) + \frac{n\theta}{2\alpha}} \delta_W, & \text{if } p_g > \breve{p}_g(\delta_W). \end{cases}$$

We now proceed to identify the equilibrium decisions of the social planner (p_g, δ_W).

THEOREM 6.2. ***(Equilibrium Support Price and Proportion Withheld)*** *The equilibrium decisions of the social planner are as follows:*

$$p_g = \begin{cases} p_m(1)^{\mathsf{NI}}, & \text{if } \eta < p_m(1)^{\mathsf{NI}}; \\ \eta, & \text{if } \eta \in [p_m(1)^{\mathsf{NI}}, \breve{p}_g(1)]; \\ \breve{p}_g(1), & \text{if } \eta > \breve{p}_g(1). \end{cases}$$

$$\delta_W = \begin{cases} 0, & \text{if } \eta < p_m(1)^{\mathsf{NI}}; \\ \breve{p}_g^{-1}(\eta), & \text{if } \eta \in [p_m(1)^{\mathsf{NI}}, \breve{p}_g(1)]; \\ 1, & \text{if } \eta > \breve{p}_g(1). \end{cases}$$

Observe that both the equilibrium support price and proportion withheld depend on η. An increase in the withholding proportion δ_W by the social planner leads to a reduction in consumption by the BPL consumers. The open-market demand curve shifts upwards since the BPL consumers are not budget-constrained. Therefore, the market-price increases. The higher market-price leads to a loss in the APL and BPL consumer surplus, but an increase in the production by the farmers. This loss in consumer surplus is offset by the higher production and the value from withheld inventory if η is high; hence δ_W is increasing in η. The equilibrium support price p_g is increasing in the market-price, and therefore increasing in η.

REMARK 6.1. **(Strategic Withholding)** From Theorem 6.1 and 6.2, the social planner's equilibrium withholding proportion $\delta_W > 0$ iff:

$$\eta > \min\left\{ \underbrace{1 - \frac{b+\beta}{p_m(1)^{\mathsf{DBT}}}}_{\underline{\eta}(p_m(1)^{\mathsf{DBT}})}, p_m(1)^{\mathsf{DBT}} \right\}. \tag{23}$$

Thus, the social planner withholds inventory if and only if the marginal value of inventory withheld is sufficiently high. In particular, strategic withholding – where the social planner withholds inventory to affect the market price – never occurs if the withheld inventory is worthless to the social planner.

6.3. Comparison with the DBT Scheme

Observe that the GSP scheme implements the outcome under the DBT scheme at $p_g = p_m(1)^{\mathsf{DBT}}$ and $\delta_W = 0$. Therefore, the social planner's surplus under the GSP scheme (weakly) dominates that under the DBT scheme. In the following result, we identify conditions under which the equilibrium production by the farmers and the social planner's surplus under the GSP scheme *strictly* dominates those under the DBT scheme.

Theorem 6.3. *Suppose η satisfies (23). Then,*

1. *The equilibrium $\delta_W > 0$. Therefore, $\Pi_S^{\mathsf{GSP}} > \Pi_S^{\mathsf{DBT}}$.*
2. *If $b > b^*(\theta)$, the equilibrium production by the farmers under* GSP *is higher than that under* DBT, *i.e., $q_e^{*\mathsf{GSP}} > q_e^{*\mathsf{DBT}}$.*

Taken together, the result above shows that the GSP scheme strictly outperforms the DBT scheme if η, the marginal value of withheld inventory, is sufficiently high; i.e., when food security is sufficiently important for the social planner. Recall that if $b > b^*(\theta)$, the DBT scheme does not improve the market outcome (relative to NI). However, under the GSP scheme, the social planner's choice of $\delta_W > 0$ leads to strictly higher production by the farmers. While an increase in δ_W hurts the consumers due to a higher market-price, this loss in consumer surplus is offset by the gain in the value from withholding inventory if η is sufficiently high.

7. Numerical Experiments

We consider two extensions of our main model – the equilibrium decisions of the social planner under unequal weights for the surplus of the various components of the social planner's objective, and the equilibrium outcome under a more general two-point distribution – using numerical experiments. Using these experiments, we illustrate the robustness of the main insights of our earlier analysis. Specifically, our goal for the first extension is to understand how different weights on the various stakeholders of the GSP scheme affect the social planner's equilibrium decisions, while in the second extension, we present the equilibrium production and the social planner's decisions under a more general two-point distribution.

7.1. A Weighted Objective of the Social Planner

In our analysis thus far, we have focused on a social planner whose objective consists of four components: the APL and BPL consumers' surplus, the farmers' surplus, the value from reserve stock, and the unused budget. From Section 1, recall that the goals of GSP scheme are three-fold: to serve as a supply-side incentive (to benefit the farmers), to serve as a demand-side provisioning tool (to supplement the BPL consumers), and to maintain an adequate amount of reserve stock (food security). Therefore, we consider an alternate objective function of the social planner where she weighs the surplus of each segment differently. Specifically, we discuss a special case where the social planner assigns the following weights, respectively, to the surplus of the BPL consumers, the surplus of the farmers, and the value from withheld inventory: $\boldsymbol{\omega} = (\omega_{BPL}, \omega_F, \omega_W) \geq 0$, where

$\omega_{BPL} + \omega_F + \omega_W = 1$.[8] While the farmers' subgame remains identical as before, the social planner's problem is:

$$\max_{p_g, \delta_W} \; \Pi_S^{\boldsymbol{\omega}} = \mathbb{E}_\gamma \left[\omega_{BPL}(kMu_{BPL}) + \omega_F(n\pi_f) + \omega_W(Q_g \delta_W) \right]. \tag{24}$$

The equilibrium decisions of the social planner under the following three special cases are as follows:

- If $\boldsymbol{\omega} = (1,0,0)$:
$$p_g = p_m(1)^{\mathsf{DBT}}, \delta_W = 0.$$
- If $\boldsymbol{\omega} = (0,1,0)$:
$$p_g = \infty, \delta_W \in [0,1].$$
- If $\boldsymbol{\omega} = (0,0,1)$:
$$p_g = \begin{cases} p_m(1)^{\mathsf{DBT}}, \text{ if } b + \beta < b^*(\theta); \\ \breve{p}_g(1), \qquad \text{if } b > b^*(\theta). \end{cases}, \delta_W = 1.$$

Furthermore, from the above, we have that $\delta_W = 1$ (resp., $\delta_W = 0$) if $\omega_{BPL} = 0$ (resp., $\omega_W = 0$). A high (resp., low) δ_W benefits (resp., hurts) the farmers and the value from the reserve stock but hurts (resp., benefits) the BPL consumers, while a high (resp., low) p_g benefits (resp., hurts) the farmers but hurts the BPL consumers and the value from the reserve stock. In Figure 1, we illustrate the equilibrium support price and the proportion withheld changes as a function of $\boldsymbol{\omega}$. For the purposes of illustration, we consider the case of $b + \beta < b^*(\theta)$. The X-axis denotes ω_W and the Y-axis denotes ω_{BPL}; for a given (ω_W, ω_{BPL}), we have $\omega_F = 1 - (\omega_W + \omega_{BPL})$. The three corner-points of the triangle correspond to the three special cases discussed above. If ω_F is small and ω_W (resp., ω_{BPL}) is large, then $p_g = p_m(1)^{\mathsf{DBT}}$ and $\delta_W = 1$ (resp., $\delta_W = 0$). Otherwise, if ω_F is large, then $p_g = \infty$ and $\delta_W \in [0,1]$.

7.2. A General Two-Point Distribution

From Theorems 6.1 and 6.2, we have the equilibrium decisions of the social planner under a Bernoulli yield distribution. In Theorem 6.3, we show that if the marginal value of reserve stock (η) is sufficiently low, then the equilibrium production quantity and the social planner's surplus are identical under the DBT and the GSP schemes; otherwise, the social planner's surplus under GSP strictly dominates that under DBT. Furthermore, if $b > b^*(\theta)$, then the production by the farmers under GSP dominates that under DBT.

[8] This choice of the social planner's objective allows us to study the effect of larger weights assigned to the surplus of the intended beneficiaries of the scheme on the equilibrium choice of the support price in a straightforward manner. Other choices of a weighted objective function, where the social planner assigns small, non-zero weights to the APL consumers' surplus and the unused budget, involve more computation but yield qualitatively similar insights.

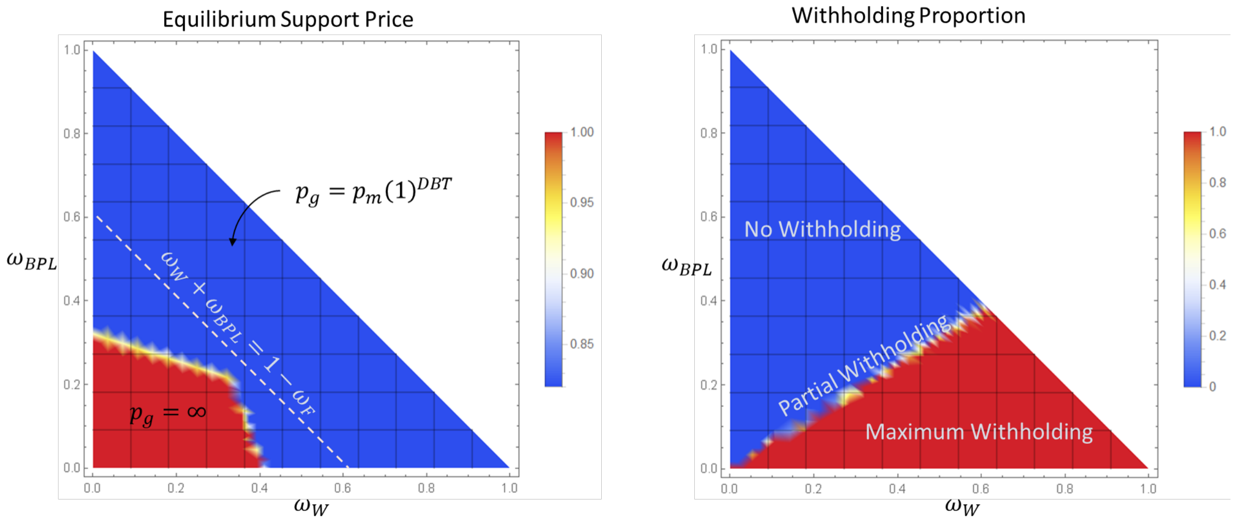

Figure 1 The equilibrium support price (left) and the proportion withheld (right) as a function of $\boldsymbol{\omega} = (\omega_{BPL}, \omega_F, \omega_W)$. The X-axis represents ω_W and the Y-axis represents ω_{BPL}. For a given pair (ω_W, ω_{BPL}), $\omega_F = 1 - (\omega_{BPL} + \omega_W)$. Values of parameters are: $M = 1, n = 1, \theta = 0.5, \alpha = 0.5, k = 5, b = 0.02, \beta = 0.03$. For these values, $b + \beta = 0.05 < b^*(\theta) = 0.071$ and $p_m(1)^{\mathsf{DBT}} = 0.82$.

In this section, we consider a general discrete distribution for the yield. Our simulation procedure is provided in Appendix C. The main technical difficulty involved is in solving for the rational-expectations equilibrium, i.e., the market price under each realization of γ. Below, we consider the following two-point distribution for the yield $\gamma \in \{\gamma_L, 1\}$, $\gamma_L < 1$:

$$\gamma = \begin{cases} \gamma_L, & \text{w.p. } 1 - \theta; \\ 1, & \text{w.p. } \theta. \end{cases}$$

For purposes of illustration, we present the outcome under the special case where γ_L is not too low. Under NI, we solve for the rational-expectations equilibrium of the game, i.e., $p_m(\gamma)$ using the market clearance condition:

$$\underbrace{M\left(1 - p_m(\gamma)\right) + kM \min\left\{\frac{b}{p_m(\gamma)}, 1 - p_m(\gamma)\right\}}_{= D(p_m(\gamma))} = n\gamma\left(\underbrace{\frac{\sum_{\gamma \in \{\gamma_L, 1\}} p_m(\gamma)\theta_\gamma \gamma}{2\alpha}}_{= q_e}\right) \quad \text{for } \gamma \in \{\gamma_L, 1\}$$

where $\theta_1 = \theta$ and $\theta_{\gamma_L} = 1 - \theta$. Under DBT, we replace $b \to b + \beta$ in the above equation. Under GSP,

- If $b + \beta$ is sufficiently low, the market-clearance condition is as follows:

$$M(1 - p_m(\gamma)) + kM\frac{b}{p_m(\gamma)} = n\left(\gamma \underbrace{\frac{\sum_{\gamma \in \{\gamma_L, 1\}} p_m(\gamma)\theta_\gamma \gamma}{2\alpha}}_{q_e} - q_g(\gamma)\right),$$

$$\text{where } q_g(\gamma) = \begin{cases} 0, & \text{if } p_g < p_m(\gamma); \\ \gamma q_e - \frac{D(p_g)}{n}, & \text{if } p_g = p_m(\gamma); \\ \frac{B}{np_g}, & \text{if } p_g > p_m(\gamma). \end{cases}$$

- If b is sufficiently high, the market-clearance condition is as follows:

$$M(1+k)(1-p_m(\gamma)) = n\left(\gamma \underbrace{\frac{\sum_{\gamma\in\{\gamma_L,1\}} p_m(\gamma)\theta_\gamma\gamma}{2\alpha}}_{q_e} - \delta_W q_g(\gamma)\right),$$

$$\text{where } q_g(\gamma) = \begin{cases} 0, & \text{if } p_g < p_m(\gamma); \\ \gamma q_e - \frac{M(1+k)(1-p_g)}{\delta_W}, & \text{if } p_g = p_m(\gamma); \\ \frac{B}{np_g}, & \text{if } p_g > p_m(\gamma). \end{cases}$$

Using numerical experiments, we analyze the equilibrium support price under the GSP scheme and compare the production effort q_e under the three settings, namely NI, DBT and GSP. We solve for the rational (equilibrium) beliefs on the market prices such that the farmers' effort leads to market prices that are consistent with their beliefs (i.e., for $\gamma \in \{\gamma_L, 1\}$, (10) and (11) hold). Under GSP, we solve for the rational beliefs corresponding to any support price p_g (i.e., on- or off-equilibrium). We detail the simulation procedure in Appendix C. For the purposes of illustration, in Figure 2, we demonstrate the total production nq_e with $\gamma_L \in \{0.5, 0.55, 0.6, \ldots, 1\}$, $\delta_W \in \{0, 0.25, 0.5, 0.75, 1\}$ and $\theta \in \{0.4, 0.6, 0.8\}$ and b is high. From the figure, we see that equilibrium production under NI, DBT, and GSP, are all increasing in θ for a given γ_L and increasing in γ_L for a given θ. Further, we find that $q_e^{*\mathsf{GSP}}$ is increasing in δ_W for given θ, γ_L.

8. Conclusions

Broadly, our goal in this paper is twofold: (a) To understand the role of Guaranteed Support Prices (GSPs) on the operational decisions of its main stakeholders, viz., the farmers, the consuming population, and the social planner (government), and (b) To understand the impact of the GSP scheme on the welfare of each stakeholder and compare them with two benchmarks: (*i*) the absence of an intervention and (*ii*) the Direct Benefit Transfer (DBT) scheme.

We compare the schemes along two dimensions: the surplus of the social planner and the total production by the farmers. Our analysis shows that the surplus of the social planner under the GSP scheme dominates that under the DBT scheme if the value from withheld inventory is sufficiently high (i.e., food security is an important concern to the social planner); otherwise, the surplus under the two schemes is identical. Two key economic forces – poorness of the below-poverty-line (BPL) consumers (a demand-side impediment) and yield uncertainty (a supply-side impediment) – act

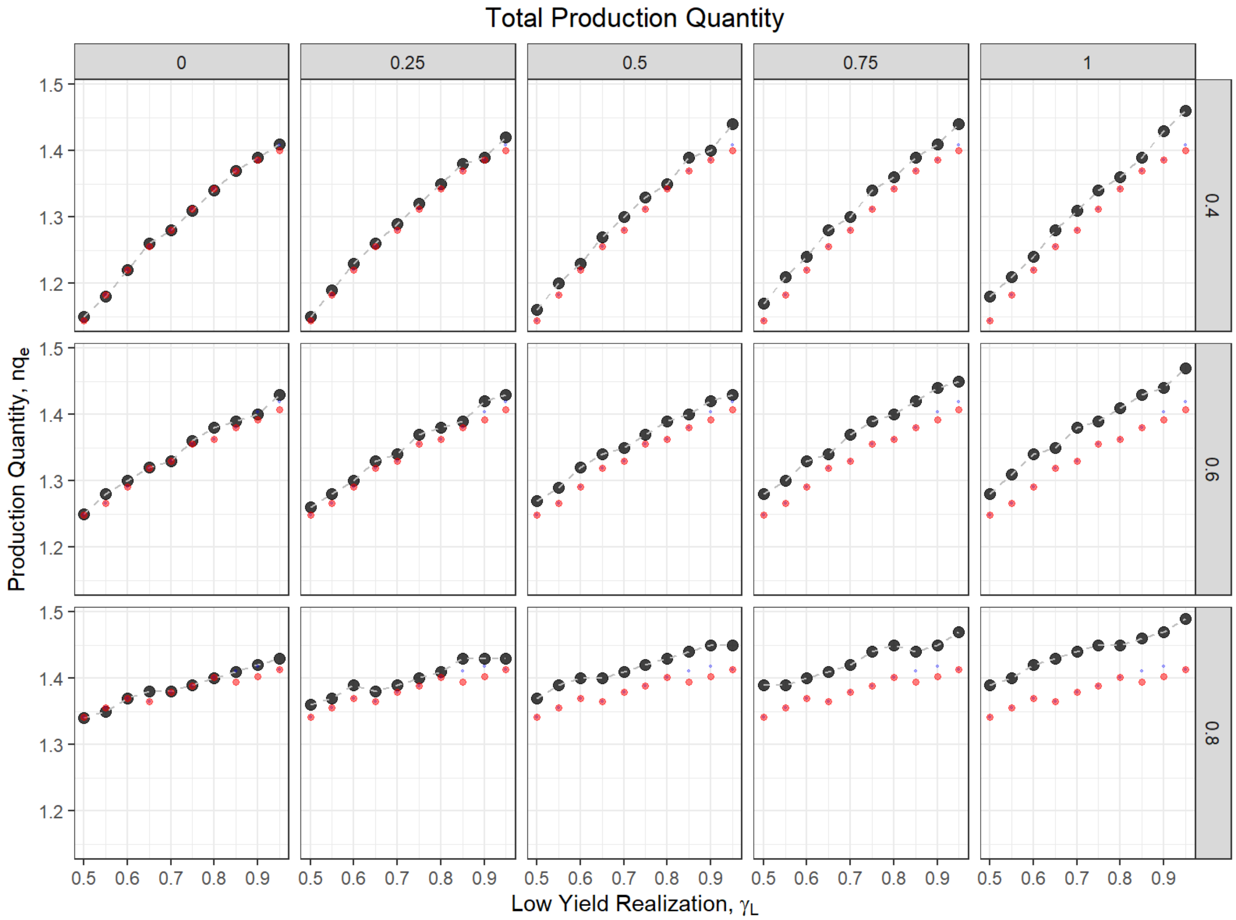

Figure 2 **The total production quantity of the farmers as a function of γ_L. The Y-axis denotes the total production quantity nq_e and the X-axis denotes the low-yield realization γ_L. The column-facet denotes the proportion of inventory withheld δ_W and the row-facet denotes the probability of high-yield realization θ. The values of the parameters used are: $M = 1, n = 1, k = 4, \alpha = 0.25, b = 0.16, \beta = 0.04, \eta = 0.2$. The production under DBT and NI are identical since yield uncertainty is dominant, and are shown by the red dots.**

as frictions to high production by the farmers and consumption by BPL consumers. If poorness is extreme, both the GSP and the DBT scheme lead to identical production by the farmers, which strictly dominates that under the absence of an intervention. If yield uncertainty is dominant, the DBT scheme is ineffective in improving the production by the farmers, while under the GSP scheme, the social planner can strategically choose the withholding proportion to improve the production by the farmers.

Our analysis focused on the GSP scheme for a single crop. In practice, many developing countries offer support prices for multiple crops; see, e.g., Planning Commission (2001). On the one hand, the government aims for crop-wise targets to "balance" their production quantities based on their relative demands from the consuming population; on the other hand, farmers – constrained by their respective geographical locations – have natural preferences over the crops but may get influenced in their choice via attractive support prices. This makes the analysis of farming effort and governmental decisions under multiple support prices a fairly complex problem. In particular, understanding the influence of support prices on the crop-mix pattern is an important and challenging problem for future research. A recent contribution along this direction is Chintapalli and Tang (2018), which considers the case of two crops.

A broader direction for future research is that of a comparison across different classes of subsidies. The World Trade Organization (WTO) classifies agricultural subsidies into *amber-box*, *blue-box*, and *green-box* subsidies (The Guardian 2013, World Trade Organization 2018): Amber-box subsidies involve support measures that can significantly distort production; the GSP scheme is one such subsidy. Green-box subsidies do not distort production at all, while blue-box subsidies only cause a moderate amount of distortion. The WTO regulates governmental spending by developing countries on these classes of subsidies – the current ceiling is 10% of the total value of agricultural production for amber-box subsidies and is 8% for blue-box subsidies. There is currently no cap on green-box subsidies, which include policies for environmental and regional protection. Thus, a comparative analysis of the tradeoffs between these classes of schemes can provide meaningful input to policymakers.

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Online Appendix to

An Economic Analysis of Agricultural Support Prices in Developing Economies

Appendix A: Main Notation

Notation	Description
	Parameters
n	The size of the farming population ($n > 0$).
α	The production-cost parameter ($\alpha > 0$).
M	The size of the APL consumer segment ($M > 0$).
k	The size of the BPL consumer segment relative to the APL consumer segment ($k > 0$).
B	The budget of the social planner ($B > 0$).
b	The wealth of a BPL consumer ($b \geq 0$).
η	The social planner's (constant) marginal utility from maintaining a reserve stock ($\eta \geq 0$).
	Decision Variables
p_g	The guaranteed support price (GSP).
δ_W	The proportion of procured crop withheld by the social planner.
q_e	The production effort exerted by a farmer.
q_m	The quantity sold by a farmer in the market
q_g	The quantity sold by a farmer to the social planner
q_{APL}	The quantity consumed by an APL consumer from the open-market.
q_{BPL}	The total quantity consumed by a BPL consumer.
	Other Variables
γ	Yield Realization
$\mathcal{Q}$	The total production effort by all farmers.
$p_m(\gamma)$	The market price under yield γ.
q_S	The quantity provided to a BPL consumer by the social planner.
	Scheme/Setting
NI	No Intervention.
DBT	Direct Benefit Transfer Scheme.
GSP	Guaranteed Support Price Scheme.

Table 1 The main notation used in our analysis.

We denote a variable of interest x under scheme/setting $t \in \{NI, DBT, GSP\}$ by x^t.

Appendix B: Proofs of Technical Results

Note: *To conserve notation in the technical proofs, we often suppress the arguments of functions when no confusion arises in doing so.*

Proof of Lemma 4.1: If $b \geq \frac{1}{4}$, then for any $p_m \in [0,1]$, we have that $0 \leq 1 - p_m \leq \frac{b}{p_m}$. Since $q_S = 0$, from (2) and (4), we have that $q^*_{BPL} = 1 - p_m$. Therefore, the total consumer demand in the open-market at a market price $p_m \in [0,1]$ is

$$D(p_m) = M(1+k)(1-p_m).$$

We assume that all farmers have the same yield realization γ and hold (identical) beliefs $\hat{p}_m(\gamma)$ about the market-price for any yield realization γ. From (9), their effort (given their beliefs about the market price) is given by

$$q^*_e = \frac{\mathbb{E}[\hat{p}_m(\gamma)\gamma]}{2\alpha}. \tag{B.1}$$

Suppose the realized yield is γ: The total quantity available in the open-market is given by $n\frac{\mathbb{E}[\hat{p}_m(\gamma)\gamma]\gamma}{2\alpha}$. Therefore, the market price (denoted by $p_m(\gamma)$) is obtained from (10) as follows:

$$M(1+k)(1-p_m(\gamma)) = \frac{n}{2\alpha}\,\mathbb{E}[\hat{p}_m(\gamma)\gamma]\gamma.$$
$$\Rightarrow p_m(\gamma) = 1 - \left(\frac{n}{2\alpha M(1+k)}\,\mathbb{E}[\hat{p}_m(\gamma)\gamma]\right)\gamma.$$

From (11), we have that $p_m(\gamma) = \hat{p}_m(\gamma)$. We substitute (11) in the above equation. Observe, from the equation above, that $p_m(\gamma)$ is linear in γ, with the intercept term equal to 1. Using this observation, we solve for $p_m(\gamma)$ and obtain the following:

$$p_m(\gamma) = 1 - \Big(\frac{\frac{n}{2\alpha}\mu}{M(1+k) + \frac{n}{2\alpha}(\mu^2+\sigma^2)}\Big)\gamma. \tag{B.2}$$

Substituting (B.2) in (B.1), we have

$$q^*_e = \frac{\mu}{2\alpha}\Big(\frac{M(1+k)}{M(1+k) + \frac{n}{2\alpha}(\mu^2+\sigma^2)}\Big).$$

■

Proof of Lemma 4.2: Consider a fixed value of $\theta \in [0,1]$. It is straightforward to see that $\hat{p}_m(0) = p_m(0) = 1$. We solve for the equilibrium value of $p_m(1)$ below. Using (9), we have that $q^*_e = \frac{\theta}{2\alpha}\hat{p}_m(1)$. Recall, from (14), that $b^*(\theta) = \frac{M(1+k)\frac{n\theta}{2\alpha}}{\left(M(1+k)+\frac{n\theta}{2\alpha}\right)^2}$. In the absence of an intervention, $q_S = 0$. Substituting (5) and (11) in (10), we have

$$M(1-p_m(1)) + kM\min\left\{1-p_m(1), \frac{b}{p_m(1)}\right\} = n\frac{\theta}{2\alpha}p_m(1). \tag{B.3}$$

Observe that the LHS of (B.3) is strictly decreasing in $p_m(1)$, while the RHS is strictly increasing in $p_m(1)$. At $p_m(1) = 1$, the LHS is strictly smaller than the RHS, while at $p_m(1) = 0$, the LHS is strictly larger than the RHS. Consequently, (B.3) has a unique solution for $p_m(1)$.

Depending on the value of b, one of the following occurs:

1. If $b > b^*(\theta)$, the solution to (B.3) is as follows:
$$p_m(1) = \frac{M(1+k)}{M(1+k)+\frac{n\theta}{2\alpha}}. \tag{B.4}$$
Further, at this value of $p_m(1)$, we have that $\frac{b}{p_m(1)} > 1 - p_m(1)$.
2. If $b < b^*(\theta)$, the solution to (B.3) is as follows:
$$p_m(1) = \frac{M + \sqrt{M^2 + 4kMb(M+\frac{n\theta}{2\alpha})}}{2(M+\frac{n\theta}{2\alpha})}. \tag{B.5}$$
Further, at this value of $p_m(1)$, we have that $\frac{b}{p_m(1)} < 1 - p_m(1)$.

Using (B.5), (B.4), the observation that (B.3) has a unique solution for $p_m(1)$, and (B.1), we have
$$q_e^* = \frac{\theta}{2\alpha} p_m(1), \text{ where } p_m(1) = \begin{cases} \frac{M(1+k)}{M(1+k)+\frac{n\theta}{2\alpha}}, & \text{if } b > b^*(\theta); \\ \frac{M+\sqrt{M^2+4kMb(M+\frac{n\theta}{2\alpha})}}{2(M+\frac{n\theta}{2\alpha})}, & \text{if } b < b^*(\theta). \end{cases}$$
■

Proof of Lemma 5.1: In this case, we have that $b+\beta < b^*(\theta)$. From Lemma 4.2 and (B.5), recall that under NI, if $b < b^*(\theta)$, the equilibrium effort of a farmer is
$$q_e^* = \frac{\theta}{2\alpha}\left(\frac{M + \sqrt{M^2 + 4kMb(M+\frac{n\theta}{2\alpha})}}{2(M+\frac{n\theta}{2\alpha})}\right),$$
and the equilibrium market price under high yield realization is
$$p_m(1) = \frac{M + \sqrt{M^2 + 4kMb(M+\frac{n\theta}{2\alpha})}}{2(M+\frac{n\theta}{2\alpha})}.$$
Both q_e^* and $p_m(1)$ above are increasing in the wealth b of a BPL consumer. Consequently, under the DBT scheme, since $b+\beta < b^*(\theta)$, the production effort and the market-price are both higher. The equilibrium quantities can be obtained by substituting $b \to (b+\beta)$ in the above expressions. Therefore, we have the first part of the result.

Using (7), under NI, the social planner's surplus can be written as follows:
$$\begin{aligned} \Pi_S^{\mathsf{NI}} &= Mw_{APL} + kMb + B + \hat{\Pi}_S^{\mathsf{NI}} \qquad \text{(B.6)} \\ \text{where } \hat{\Pi}_S^{\mathsf{NI}} &= -n\alpha\left(\frac{\theta}{2\alpha}p_m(1)^{\mathsf{NI}}\right)^2 + \theta\left(M\int_0^{1-p_m(1)^{\mathsf{NI}}}(1-\xi)d\xi + kM\int_0^{\frac{b}{p_m(1)^{\mathsf{NI}}}}(1-\xi)d\xi\right), \\ \text{and } p_m(1)^{\mathsf{NI}} &= \frac{M + \sqrt{M^2 + 4kMb(M+\frac{n\theta}{2\alpha})}}{2(M+\frac{n\theta}{2\alpha})} \end{aligned}$$

Similarly, under the DBT scheme, the social planner's surplus can be written as
$$\begin{aligned} \Pi_S^{\mathsf{DBT}} &= Mw_{APL} + kM(b+\beta) + \hat{\Pi}_S^{\mathsf{DBT}} \qquad \text{(B.7)} \\ \text{where } \hat{\Pi}_S^{\mathsf{DBT}} &= -n\alpha\left(\frac{\theta}{2\alpha}p_m(1)^{\mathsf{DBT}}\right)^2 + \theta\left(M\int_0^{1-p_m(1)^{\mathsf{DBT}}}(1-\xi)d\xi + kM\int_0^{\frac{b+\beta}{p_m(1)^{\mathsf{DBT}}}}(1-\xi)d\xi\right), \\ \text{and } p_m(1)^{\mathsf{DBT}} &= \frac{M + \sqrt{M^2 + 4kM(b+\beta)(M+\frac{n\theta}{2\alpha})}}{2(M+\frac{n\theta}{2\alpha})}. \end{aligned}$$

We show that the difference in the social planner's surplus under DBT and NI, i.e., the difference in the RHS of (B.7) and (B.6) is strictly positive. Observe that the first terms of (B.6) and (B.7) are identical (the wealth across all segments). Consequently, it is sufficient to show that the difference, $\hat{\Pi}_S^{\mathsf{DBT}} - \hat{\Pi}_S^{\mathsf{NI}}$, is strictly positive. Further, it suffices to show that $\frac{d\hat{\Pi}_S^{\mathsf{NI}}}{db} > 0$. From (B.6):

$$\frac{d\hat{\Pi}_S^{\mathsf{NI}}}{db} = \theta\left(-p_m(1)^{\mathsf{NI}}\frac{dp_m(1)^{\mathsf{NI}}}{db}\left(n\frac{\theta}{2\alpha}+M\right)+kM\left(1-\frac{b}{p_m(1)^{\mathsf{NI}}}\right)\frac{d}{db}\left(\frac{b}{p_m(1)^{\mathsf{NI}}}\right)\right) \tag{B.8}$$

Using the market-clearance condition under NI in (B.3), we have the following:

$$kM\frac{d}{db}\left(\frac{b}{p_m(1)^{\mathsf{NI}}}\right) = \left(M+n\frac{\theta}{2\alpha}\right)\frac{dp_m(1)^{\mathsf{NI}}}{db}. \tag{B.9}$$

Substituting (B.9) in (B.8), we have

$$\frac{d\hat{\Pi}_S^{\mathsf{NI}}}{db} = \theta\left(M+n\frac{\theta}{2\alpha}\right)\left(\underbrace{1-p_m(1)^{\mathsf{NI}}}_{=q_{APL}} - \underbrace{\frac{b}{p_m(1)^{\mathsf{NI}}}}_{=q_{BPL}}\right)\frac{dp_m(1)^{\mathsf{NI}}}{db}$$

Each of the above terms are positive; hence, $\hat{\Pi}_S^{\mathsf{NI}}$ is increasing in b. Thus, $\hat{\Pi}_S^{\mathsf{DBT}} > \hat{\Pi}_S^{\mathsf{NI}}$. ■

Proof of Lemma 6.1: Consider an announced support price p_g and a proportion withheld δ_W. We can succinctly write the farmer's problem as:

$$\max_{q_e \geq 0} \pi_f = -\alpha q_e^2 + \mathbb{E}_\gamma\left[r^\gamma(q_e)\right] \quad (\text{Problem } \mathsf{P}_{\mathsf{f}}^2)$$
$$\text{where } r^\gamma(q_e) = \max_{0\leq q_g \leq \min\left\{\gamma q_e, \frac{B}{np_g}\right\}} \left[p_g q_g + \hat{p}_m(\gamma)(\gamma q_e - q_g)\right] \quad (\text{Problem } \mathsf{P}_{\mathsf{f}}^1)$$

Observe that for given $\hat{p}_m(\gamma)$, the farmer's problem is independent of δ_W. Since $\gamma \sim Bernoulli(\theta)$ and $\hat{p}_m$, we can combine the two problems above as follows:

$$\max_{q_e\geq 0, q_g \in \left[0, \min\left\{q_e, \frac{B}{np_g}\right\}\right]} \pi_f = -\alpha q_e^2 + \theta\left((p_g - \hat{p}_m(1))q_g + \hat{p}_m(1)q_e\right).$$

One of the following holds:

(*a*) $p_g < \hat{p}_m(1)$,

(*b*) $p_g = \hat{p}_m(1)$,

(*c*) $p_g > \hat{p}_m(1)$.

If (*a*) holds, the above problem is straightforward: the farmer's decisions are $q_g = 0$ and $q_e = \frac{\theta}{2\alpha}\hat{p}_m(1)$.
If (*b*) holds, then the farmer is indifferent between selling to the social planner or the open-market. Therefore, the optimal decisions of the farmer is $q_e = \frac{\theta}{2\alpha}\hat{p}_m(1)$ and $q_g \in \left[0, \min\left\{q_e, \frac{B}{np_g}\right\}\right]$.
If (*c*) holds, we write the Lagrangian is as follows:

$$Ł = \pi_f + \lambda_1\left(\frac{B}{np_g}\right) + \lambda_2\left(q_e - q_g\right).$$

The FOC's are:

$$\frac{\partial Ł}{\partial q_e} = 0 \implies q_e = \frac{\theta}{2\alpha}\hat{p}_m(1) + \frac{1}{2\alpha}\lambda_2.$$
$$\frac{\partial Ł}{\partial q_g} = 0 \implies \theta(p_g - \hat{p}_m(1)) = \lambda_1 + \lambda_2$$
$$\lambda_1\left(\frac{B}{np_g} - q_g\right) = 0, \qquad \lambda_2\left(q_e - q_g\right) = 0.$$

One of the following holds:

- $\lambda_1 = \lambda_2 = 0$: This case occurs if $p_g = \hat{p}_m(1)$. $q_e = \frac{\theta}{2\alpha}\hat{p}_m(1)$. Any $q_g \le \min\left\{\frac{B}{np_g}, q_e\right\}$ is optimal
- $\lambda_1 > 0, \lambda_2 = 0$: This case occurs if: $p_g > \hat{p}_m(1)$ and $\frac{B}{np_g} \le \frac{\theta}{2\alpha}\hat{p}_m(1)$. $q_e = \frac{\theta}{2\alpha}\hat{p}_m(1)$, $q_g = \frac{B}{np_g}$.
- $\lambda_1 = 0, \lambda_2 > 0$: This case occurs if: $p_g > \hat{p}_m(1)$ and $\frac{\theta}{2\alpha}p_g \le \frac{B}{np_g}$. $q_e = q_g = \frac{\theta}{2\alpha}p_g$.
- $\lambda_1 > 0, \lambda_2 > 0$: This case occurs if: $p_g > \hat{p}_m(1)$ and $\frac{\theta}{2\alpha}\hat{p}_m(1) \le \frac{B}{np_g} \le \frac{\theta}{2\alpha}p_g$. $q_e = q_g = \frac{B}{np_g}$.

Combining the observations above, we summarize the solution to the farmer's problem under each case.

(*a*) $p_g < \hat{p}_m(1)$: $q_e = \frac{\theta}{2\alpha}\hat{p}_m(1)$, $q_g = 0$.

(*b*) $p_g = \hat{p}_m(1)$: $q_e = \frac{\theta}{2\alpha}\hat{p}_m(1)$, $q_g \in \left[0, \min\left\{\frac{B}{np_g}, q_e\right\}\right]$.

(*c*) $p_g > \hat{p}_m(1)$:

$$q_e = \begin{cases} \frac{\theta}{2\alpha}\hat{p}_m(1), & \text{if } \frac{B}{np_g} \le \frac{\theta}{2\alpha}\hat{p}_m(1) \le \frac{\theta}{2\alpha}p_g; \\ \frac{B}{np_g}, & \text{if } \frac{\theta}{2\alpha}\hat{p}_m(1) \le \frac{B}{np_g} \le \frac{\theta}{2\alpha}p_g; \\ \frac{\theta}{2\alpha}p_g, & \text{if } \frac{\theta}{2\alpha}\hat{p}_m(1) \le \frac{\theta}{2\alpha}p_g \le \frac{B}{np_g}. \end{cases} \qquad q_g = \min\left\{\frac{B}{np_g}, q_e\right\}.$$

■

Proof of Lemma 6.2: Using Lemma 6.1, we have the farmer's production and selling decisions for any p_g, δ_W of the social planner, and any given beliefs $\hat{p}_m(\gamma)$. We now solve for the REE, i.e., we identify the only rational beliefs on the market price in any subgame.

We divide the proof into three cases:

(*a*) $p_g < p_m(1)^{\mathsf{NI}}$,

(*b*) $p_g \in [p_m(1)^{\mathsf{NI}}, p_m(1)^{\mathsf{DBT}}]$,

(*c*) $p_g > p_m(1)^{\mathsf{DBT}}$.

Consider case (*a*), where $p_g < p_m(1)^{\mathsf{NI}}$. We show that the only rational beliefs $\hat{p}_m(1) = p_m(1)$ are such that $p_g < p_m(1) = p_m(1)^{\mathsf{NI}}$. Suppose not, i.e., suppose that $p_m(1) \le p_g < p_m(1)^{\mathsf{NI}}$. Then, using Assumption 5.1, we have that $q_e = \frac{\theta}{2\alpha}p_m(1)$. Since $p_m(1) \le p_g$, the optimal decision of the farmers involves $q_g \ge 0$. The market clearance condition can be written as follows:

$$M(1 - p_m(1)) + kM\min\left\{\frac{b}{p_m(1)}, 1 - p_m(1) - \frac{n}{kM}q_g(1 - \delta_W)\right\} = n\left(\frac{\theta}{2\alpha}p_m(1) - q_g\right). \tag{B.10}$$

The LHS is decreasing in $p_m(1)$ while the RHS is increasing in $p_m(1)$. Further, using Lemma 4.2, the market-clearance condition above holds as an equality at $p_m(1) = p_m(1)^{\mathsf{NI}}$ and $q_g = 0$. Therefore, it is impossible that (B.10) holds as an equality at any $p_m(1) < p_m(1)^{\mathsf{NI}}$ and $q_g \ge 0$. Therefore, the only rational beliefs under case (*a*) involves

$$p_g < \hat{p}_m(1) = p_m(1) = p_m(1)^{\mathsf{NI}} \implies q_e = \frac{\theta}{2\alpha}p_m(1)^{\mathsf{NI}}, q_g = 0 \text{ (from Lemma 6.1)}.$$

The proof of cases (*b*) and (*c*) are identical to that of case (*a*) above. In case (*b*), i.e., $p_g \in \left[p_m(1)^{\mathsf{NI}}, p_m(1)^{\mathsf{DBT}}\right]$, we have that the only rational beliefs of the farmers involves $p_g = \hat{p}_m(1) = p_m(1)$. We focus on symmetric strategies for the farmers. Using Lemma 6.1, we have that

$$q_e = \frac{\theta}{2\alpha}p_g, \;\; q_g = \frac{\theta}{2\alpha}p_g - \frac{1}{n}\left(M(1 - p_g) + kM\frac{b}{p_g}\right).$$

In case (c), i.e., $p_g > p_m(1)^{\mathsf{DBT}}$, we have that the only rational beliefs of the farmers involves $p_g > \hat{p}_m(1) = p_m(1)$. Using Lemma 6.1 and Assumption 5.1, we have that

$$M(1-p_m(1)) + kM\min\left\{\frac{b}{p_m(1)}, 1-p_m(1) - \frac{\beta}{p_g}(1-\delta_W)\right\} = n\left(\frac{\theta}{2\alpha}p_m(1) - \frac{B}{np_g}\right)$$

Since $b+\beta < b^*(\theta)$, we have that

$$M(1-p_m(1)) + kM\left(\frac{b}{p_m(1)} + \frac{\beta}{p_g}\right) = n\frac{\theta}{2\alpha}p_m(1)$$

$$\implies p_m(1) = \frac{\left(M + kM\frac{\beta}{p_g}\right) + \sqrt{\left(M + kM\frac{\beta}{p_g}\right)^2 + 4kMb\left(M + \frac{n\theta}{2\alpha}\right)}}{2\left(M + \frac{n\theta}{2\alpha}\right)}.$$

■

Proof of Theorem 6.1: Recall the social planner's surplus under the GSP scheme from (7).

$$\hat{\Pi}_S = -n\alpha\left(\frac{\theta}{2\alpha}p_m(1)\right)^2 + \theta\Bigg(M\int_0^{1-p_m(1)}(1-\xi)d\xi + kM\int_0^{\frac{1}{kM}\left(n\frac{\theta}{2\alpha}p_m(1) - M(1-p_m(1)) - Q_g\delta_W\right)}(1-\xi)d\xi + \eta\left(Q_g\delta_W\right)\Bigg).$$

The quantity procured by the social planner is as follows:

$$Q_g = nq_g = \begin{cases} 0, & \text{if } p_g < p_m(1)^{\mathsf{NI}}; \\ n(\frac{\theta}{2\alpha}p_g) - \left(M(1-p_g) + kM\frac{b}{p_g}\right), & \text{if } p_g \in [p_m(1)^{\mathsf{NI}}, p_m(1)^{\mathsf{DBT}}]; \\ \frac{B}{p_g}, & \text{if } p_g > p_m(1)^{\mathsf{DBT}}. \end{cases}$$

(a) The outcome under $p_g < p_m(1)^{\mathsf{NI}}$ is straightforward, and is identical to that under NI.

(b) Consider a fixed $p_g \in [p_m(1)^{\mathsf{NI}}, p_m(1)^{\mathsf{DBT}}]$. The social planner's surplus can be written as:

$$\hat{\Pi}_S = -n\alpha\left(\frac{\theta}{2\alpha}p_g\right)^2 + \theta\left(M\int_0^{1-p_g}(1-\xi)d\xi + kM\int_0^{\frac{b}{p_g}+\frac{Q_g}{kM}(1-\delta_W)}(1-\xi)d\xi + \eta\left(Q_g\delta_W\right)\right).$$

Therefore, $\frac{d\hat{\Pi}_S}{d\delta_W}$ is as follows:

$$\frac{d\hat{\Pi}_S}{d\delta_W} = \theta Q_g\left(\underbrace{\eta}_{\text{Marginal Value from withholding}} - \underbrace{\left(1 - \overbrace{\left(\frac{b}{p_g} + \frac{Q_g}{kM}(1-\delta_W)\right)}^{=q_{BPL}}\right)}_{=u'(q_{BPL}),\ \text{marginal consumption utility by a BPL consumer}}\right)$$

Thus, the sign of $\frac{d\hat{\Pi}_S}{d\delta_W}$ depends on $\eta - u'(q_{BPL})$, i.e., the net of the marginal value from withholding and the marginal consumption utility by a BPL consumer. Corresponding to an announced p_g, recall the definition of $\underline{\eta}(p_g)$ and $\overline{\eta}(p_g)$ from (21) as follows:

$$\underline{\eta}(p_g) = 1 - \left(\frac{b}{p_g} + \frac{Q_g}{kM}\right)$$
$$\overline{\eta}(p_g) = 1 - \frac{b}{p_g},$$

Observe that $\underline{\eta}(p_g)$ (resp., $\overline{\eta}(p_g)$) is decreasing (resp., increasing) in p_g; $\underline{\eta}(p_m(1)^{\mathsf{NI}}) = \overline{\eta}(p_m(1)^{\mathsf{NI}}) = 1 - \frac{b}{p_m(1)^{\mathsf{NI}}}$. For a fixed p_g and a given η, one of the following holds:

- If $\eta < \underline{\eta}(p_g)$, then, the optimal value of $\delta_W = 1$.
- If $\eta > \overline{\eta}(p_g)$, then, the optimal value of $\delta_W = 0$.
- If $\eta \in [\underline{\eta}(p_g), \overline{\eta}(p_g)]$, then, the optimal δ_W solves:

$$\eta = 1 - \left(\frac{b}{p_g} + \frac{Q_g}{kM}(1-\delta_W)\right) \implies \delta_W(p_g) = \frac{\eta - \underline{\eta}^{p_g}}{\frac{Q_g}{kM}}.$$

Taken together, the above statements can be summarized as follows:

- If $\eta < \underline{\eta}(p_m(1)^{\mathsf{DBT}}) \left(= 1 - \frac{b+\beta}{p_m(1)^{\mathsf{DBT}}}\right)$: For all values of p_g, we have that $\delta_W = 0$.
- If $\eta > \overline{\eta}(p_m(1)^{\mathsf{DBT}}) \left(= 1 - \frac{b}{p_m(1)^{\mathsf{DBT}}}\right)$: For all values of p_g, we have that resp., $\delta_W = 1$.
- If $\eta \in [\underline{\eta}(p_m(1)^{\mathsf{DBT}}), \overline{\eta}(p_m(1)^{\mathsf{DBT}})]$: Define $\underline{\hat{p}}_g$ as:

$$\underline{\hat{p}}_g \text{ solves } \begin{cases} \eta = \underline{\eta}(\underline{\hat{p}}_g), \text{ if } \eta < \underline{\eta}(p_m(1)^{\mathsf{NI}}); \\ \eta = \overline{\eta}(\underline{\hat{p}}_g), \text{ if } \eta > \overline{\eta}(p_m(1)^{\mathsf{NI}}). \end{cases}$$

Then,

$$\text{If } \eta < \underline{\eta}(p_m(1)^{\mathsf{NI}}), \text{ then, } \delta_W = \begin{cases} 0, & \text{if } p_g < \underline{\hat{p}}_g; \\ \frac{\eta - \underline{\eta}(p_g)}{\frac{Q_g}{kM}}, & \text{if } p_g > \underline{\hat{p}}_g. \end{cases}$$

$$\text{If } \eta > \overline{\eta}(p_m(1)^{\mathsf{NI}}), \text{ then, } \delta_W = \begin{cases} 1, & \text{if } p_g < \underline{\hat{p}}_g; \\ \frac{\eta - \underline{\eta}(p_g)}{\frac{Q_g}{kM}}, & \text{if } p_g > \underline{\hat{p}}_g. \end{cases}$$

(c) Consider $p_g > p_m(1)^{\mathsf{DBT}}$: In this case, $Q_g = \frac{B}{p_g}$. Thus,

$$\frac{d\hat{\Pi}_S}{d\delta_W} = \theta \frac{B}{p_g}\left(\underbrace{\eta}_{\text{marginal value from withholding}} - \underbrace{\left(1 - \left(\frac{b}{p_m(1)} + \frac{\beta}{p_g}(1-\delta_W)\right)\right)}_{\text{marginal consumption utility by a BPL consumer}}\right).$$

In this case, we have $\underline{\eta}(p_g)$ and $\overline{\eta}(p_g)$ as follows:

$$\begin{aligned} \underline{\eta}(p_g) &= 1 - \left(\frac{b}{p_m(1)} + \frac{\beta}{p_g}\right) \\ \overline{\eta}(p_g) &= 1 - \frac{b}{p_m(1)}. \end{aligned}$$

Observe that $\overline{\eta}(p_g)$ (resp., $\underline{\eta}(p_g)$) is decreasing (resp., increasing) in p_g; $\lim_{p_g \to \infty} \underline{\eta}^{p_g} = \lim_{p_g \to \infty} \overline{\eta}^{p_g} = 1 - \frac{b}{p_m(1)^{\mathsf{NI}}}$. For a fixed $p_g > p_m(1)^{\mathsf{DBT}}$ and a given η, one of the following holds:

- If $\eta < \underline{\eta}(p_g)$: The optimal $\delta_W = 0$.
- If $\eta > \overline{\eta}(p_g)$: The optimal $\delta_W = 1$
- If $\eta \in [\underline{\eta}(p_g), \overline{\eta}(p_g)]$: The optimal δ_W solves:

$$\eta = 1 - \left(\frac{b}{p_m(1)} + \frac{\beta}{p_g}(1-\delta_W)\right) \implies \delta_W = \frac{\eta - \underline{\eta}(p_g)}{\frac{\beta}{p_g}}.$$

Based on the outcome in the cases (a)-(c),

- If $\eta > \overline{\eta}(p_m(1)^{\mathsf{DBT}})$: The optimal $\delta_W = 1$ for all p_g.
- If $\eta < \underline{\eta}(p_m(1)^{\mathsf{DBT}})$: The optimal $\delta_W = 0$ for all p_g.

- If $\eta \in [\underline{\eta}(p_m(1)^{\mathsf{DBT}}), \overline{\eta}(p_m(1)^{\mathsf{DBT}})]$: Define $\bar{\hat{p}}_g$ as:

$$\bar{\hat{p}}_g \text{ solves } \begin{cases} \eta = \underline{\eta}(\bar{\hat{p}}_g), \text{ if } \eta < \underline{\eta}(p_m(1)^{\mathsf{NI}}); \\ \eta = \overline{\eta}(\bar{\hat{p}}_g), \text{ if } \eta > \overline{\eta}(p_m(1)^{\mathsf{NI}}). \end{cases}$$

Then,

$$\text{If } \eta < \underline{\eta}(p_m(1)^{\mathsf{NI}}), \text{ then, } \delta_W = \begin{cases} \frac{\eta - \eta(p_g)}{\frac{\beta}{p_g}}, \text{ if } p_g < \bar{\hat{p}}_g; \\ 0, \quad\quad \text{ if } p_g > \bar{\hat{p}}_g. \end{cases}$$

$$\text{If } \eta > \overline{\eta}(p_m(1)^{\mathsf{NI}}), \text{ then, } \delta_W = \begin{cases} \frac{\eta - \eta(p_g)}{\frac{\beta}{p_g}}, \text{ if } p_g < \bar{\hat{p}}_g; \\ 1, \quad\quad \text{ if } p_g > \bar{\hat{p}}_g. \end{cases}$$

Thus, there are three regions:

- If $\eta < \underline{\eta}(p_m(1)^{\mathsf{DBT}})$: The equilibrium $\delta_W = 0$ for any p_g. Substituting $\delta_W = 0$ in Π_S, we have the following:

$$\hat{\Pi}_S = -n\alpha \left(\frac{\theta}{2\alpha} p_m(1) \right)^2 + \theta \left(M \int_0^{1-p_m(1)} (1-\xi) d\xi + kM \int_0^{\frac{b}{p_m(1)} + q_S} (1-\xi) d\xi \right)$$

where $q_S = \frac{n}{kM} q_g$. Using first order conditions and the market-clearance conditions, we have that

$$\frac{d\hat{\Pi}_S}{dp_g} = \theta kM \left(\underbrace{1 - p_m(1)}_{= q_{APL}} - \left(\underbrace{\frac{b}{p_m(1)} + q_S}_{= q_{BPL}} \right) \right) \frac{dp_m(1)}{dp_g}$$

The first and the second terms in the RHS above are strictly positive. From Lemma 6.2, the last term in RHS above is positive if $p_g < p_m(1)^{\mathsf{DBT}}$ and negative if $p_g > p_m(1)^{\mathsf{DBT}}$. Therefore, the equilibrium $p_g = p_m(1)^{\mathsf{DBT}}$.

- If $\eta > \overline{\eta}(p_m(1)^{\mathsf{DBT}})$: The equilibrium $\delta_W = 1$. Substituting $\delta_W = 1$ in Π_S, we have the following:

$$\hat{\Pi}_S = -n\alpha \left(\frac{\theta}{2\alpha} p_m(1) \right)^2 + \theta \left(M \int_0^{1-p_m(1)} (1-\xi) d\xi + kM \int_0^{\frac{b}{p_m(1)}} (1-\xi) d\xi + \eta Q_g \right)$$

Using the market clearance conditions, we have:

$$\begin{aligned} \frac{d\hat{\Pi}_S}{dp_g} &= \theta \left(kM \left(1 - p_m(1) - \frac{b}{p_m(1)} \right) \frac{d}{dp_g} \left(\frac{b}{p_m(1)} \right) + (\eta - p_m(1)) \frac{dQ_g}{dp_g} \right) \\ &= \begin{cases} \theta \left(kM \left(1 - \frac{b}{p_g} - \eta \right) \frac{d}{dp_g} \left(\frac{b}{p_g} \right) + \left(M + n\frac{\theta}{2\alpha} \right) (\eta - p_g) \right), & p_g \in [p_m(1)^{\mathsf{NI}}, p_m(1)^{\mathsf{DBT}}]; \\ \theta \left(\left(1 - p_m(1) - \frac{b}{p_m(1)} \right) \left(M + n\frac{\theta}{2\alpha} \right) \frac{dp_m(1)}{dp_g} + kM \frac{d}{dp_g} \left(\frac{\beta}{p_g} \right) \right), & p_g > p_m(1)^{\mathsf{DBT}} \end{cases} \end{aligned}$$

From above, $\frac{d\hat{\Pi}_S}{dp_g}$ is positive (resp., negative) in $p_g \in \left[p_m(1)^{\mathsf{NI}}, p_m(1)^{\mathsf{DBT}} \right]$ (resp., $p_g > p_m(1)^{\mathsf{DBT}}$).

- If $\eta \in [\underline{\eta}(p_m(1)^{\mathsf{DBT}}), \overline{\eta}(p_m(1)^{\mathsf{DBT}})]$: From the above analysis, if $\eta < \underline{\eta}(p_m(1)^{\mathsf{NI}})$ (resp., $\eta > \underline{\eta}(p_m(1)^{\mathsf{NI}})$), then $\delta_W = \frac{\eta - \eta(p_g)}{\frac{Q_g}{kM}}$ if $p_g \in [\underline{\hat{p}}_g, \bar{\hat{p}}_g]$ and 0 (resp., 1) otherwise. Based on the analysis in the two cases above, the social planner's surplus is increasing in $p_g \in [p_m(1)^{\mathsf{NI}}, \underline{\hat{p}}_g]$ and decreasing in $p_g > \bar{\hat{p}}_g$. Thus, the equilibrium support price lies in $p_g \in [\underline{\hat{p}}_g, \bar{\hat{p}}_g]$. Further, Π_S is increasing (resp., decreasing) in $p_g \in [\underline{\hat{p}}_g, p_m(1)^{\mathsf{DBT}}]$ (resp., $p_g \in [p_m(1)^{\mathsf{DBT}}, \bar{\hat{p}}_g]$). Consider the case where $\eta \in [\underline{\eta}(p_m(1)^{\mathsf{DBT}}), \underline{\eta}(p_m(1)^{\mathsf{NI}})]$:

$$\begin{aligned} \frac{d\hat{\Pi}_S}{dp_g} &= \theta \left(-p_m(1) \left(n\frac{\theta}{2\alpha} + M \right) \frac{dp_m(1)}{dp_g} + \eta \frac{d}{dp_g} (Q_g \delta_W) \right) \\ &= \theta \left((\eta - p_m(1)) \frac{d}{dp_g} \left(n\frac{\theta}{2\alpha} p_m(1) - M(1 - p_m(1)) \right) \right) \end{aligned}$$

The first term is always positive. The second term is positive in $p_g < p_m(1)^{\mathsf{DBT}}$ and negative in $p_g > p_m(1)^{\mathsf{DBT}}$. Thus, the equilibrium $p_g = p_m(1)^{\mathsf{DBT}}$. The proof of the case $\eta \in [\overline{\eta}(p_m(1)^{\mathsf{NI}}), \overline{\eta}(p_m(1)^{\mathsf{DBT}})]$ is identical. Therefore, the equilibrium is $p_g = p_m(1)^{\mathsf{DBT}}$ and $\delta_W = \frac{\frac{\eta - \underline{\eta}(p_g)}{\beta}}{p_m(1)^{\mathsf{DBT}}}$.

■

Proof of Lemma 6.3: Consider a fixed δ_W. Recall the definition of $\breve{p}_g$ from (22). The proof consists of three cases:

(*a*) $p_g < p_m(1)^{\mathsf{NI}}$,

(*b*) $p_g \in [p_m(1)^{\mathsf{NI}}, \breve{p}_g(\delta_W)]$,

(*c*) $p_g > \breve{p}_g(\delta_W)$.

Consider case (*a*), where $p_g < p_m(1)^{\mathsf{NI}}$. We show that the unique REE involves $p_g < p_m(1) = p_m(1)^{\mathsf{NI}}$. Suppose not, i.e., suppose $p_m(1) \le p_g < p_m(1)^{\mathsf{NI}}$. Then, from Lemma 6.1, we have that $q_g \ge 0$. The market clearance condition can be written as:

$$M(1 - p_m(1)) + kM \min\left\{\frac{b}{p_m(1)}, 1 - p_m(1) - \frac{n}{kM} q_g (1 - \delta_W)\right\} = n\left(\frac{\theta}{2\alpha} p_m(1) - q_g\right)$$

Since $b > b^*(\theta)$, we have that

$$M(1+k)(1 - p_m(1)) = n\left(\frac{\theta}{2\alpha} p_m(1) - q_g\right)$$

The LHS is decreasing in $p_m(1)$, while the RHS is increasing in $p_m(1)$. Further, the above market-clearance condition holds as an equality at $p_m(1) = p_m(1)^{\mathsf{NI}}$ and $q_g = 0$. Therefore, it is impossible that it holds for any $p_m(1) < p_m(1)^{\mathsf{NI}}$ and $q_g \ge 0$. Therefore, the only rational beliefs are $p_g < p_m(1)$. Using Lemma 6.1, we have that $q_e = \frac{\theta}{2\alpha} p_m(1)$ and $q_g = 0$. Substituting this in the market-clearance condition, we get $p_m(1) = p_m(1)^{\mathsf{NI}}$.

The proof of cases (*b*) and (*c*) are identical. Under case (*b*), we show that the unique REE involves $p_g = p_m(1)$, while under case (*c*), we have that the unique REE is $p_g > p_m(1)$. From Lemma 6.1, we have that $q_e = \frac{\theta}{2\alpha} p_m(1)$. Since $b > b^*(\theta)$, we have that $q_g = \min\left\{\frac{B}{np_g}, \frac{\theta}{2\alpha} p_g - M(1+k)(1-p_g)\right\}$. ■

Proof of Theorem 6.3: The proof consists of three cases. Consider a fixed δ_W. We identify the optimal p_g for a given δ_W, and then identify the equilibrium δ_W.

Consider a fixed δ_W. We consider the following cases:

(*a*) $p_g < p_m(1)^{\mathsf{NI}}$.

(*b*) $p_g \in [p_m(1)^{\mathsf{NI}}, \breve{p}_g(\delta_W)]$.

(*c*) $p_g > \breve{p}_g(\delta_W)$.

The analysis in case (*a*) is straightforward, and identical to NI. Under case (*b*) and (*c*), we have that:

$$\frac{d\hat{\Pi}_S}{dp_g} = \theta\left(M(1+k) + n\frac{\theta}{2\alpha}\right)(\eta - p_m(1))\frac{dp_m(1)}{dp_g}.$$

From Lemma 6.2, $p_m(1)$ is increasing in $p_g \in [p_m(1)^{\mathsf{NI}}, \breve{p}_g(\delta_W)]$ and decreasing in $p_g > \breve{p}_g(\delta_W)$. Therefore, we have the following:

- If $\eta < p_m(1)^{\mathsf{NI}}$, Π_S is decreasing in $p_g \in [p_m(1)^{\mathsf{NI}}, \breve{p}_g(\delta_W)]$ and increases in $p_g > \breve{p}_g(\delta_W)$ for any δ_W. Thus, the optimal support price is either $p_g = p_m(1)^{\mathsf{NI}}$ or ∞.

- If $\eta > \breve{p}_g(\delta_W)$, Π_S is increasing in $p_g \in [p_m(1)^{\mathsf{NI}}, \breve{p}_g(\delta_W)]$ and decreasing in $p_g > \breve{p}_g(\delta_W)$. Thus, the optimal $p_g = \breve{p}_g(\delta_W)$.
- If $\eta \in [p_m(1)^{\mathsf{NI}}, \breve{p}_g(\delta_W)]$: There are two optimal solutions:

$$p_g = \eta\,(<\breve{p}_g(\delta_W)) \text{ or } \underbrace{p_g = \frac{B\delta_W}{\left(M(1+k)+n\frac{\theta}{2\alpha}\right)(\eta - p_m(1)^{\mathsf{NI}})}}_{\implies p_m(1)=\eta}(>\breve{p}_g(\delta_W))\,.$$

  Both these solutions are outcome-equivalent and lead to an identical surplus to the social planner. For convenience, we choose $p_g = \eta$.

Taken together, the above solutions lead to the following:

- If $\eta < p_m(1)^{\mathsf{NI}}$, the equilibrium support price is $p_g = p_m(1)^{\mathsf{NI}}$. Thus, $p_g = p_m(1)^{\mathsf{NI}}, \delta_W = 0$ constitutes an equilibrium.
- If $\eta > \breve{p}_g(1)$, the optimal solution for a given δ_W is $p_g = \breve{p}_g$. To identify the optimal δ_W, observe that:

$$\frac{d\hat{\Pi}_S}{d\delta_W}\Big|_{p_g=\breve{p}_g(\delta_W)} = \theta\left(M(1+k)+n\frac{\theta}{2\alpha}\right)(\eta - \breve{p}_g(\delta_W))\,\frac{d\breve{p}_g}{d\delta_W}$$

  Since $\eta > \breve{p}_g(1)$ and $\breve{p}_g$ is increasing in δ_W, the RHS above is strictly positive. Therefore, we have that the equilibrium $\delta_W = 1$.
- If $\eta \in [p_m(1)^{\mathsf{NI}}, \breve{p}_g(1)]$: Combining the last two cases above, we have that the equilibrium $p_g = \eta$ and the equilibrium δ_W is such that:

$$\eta = \breve{p}_g(\delta_W) \implies \delta_W = \breve{p}_g^{-1}(\eta).$$

$\blacksquare$

Appendix C: Simulation Procedure for Numerical Experiments

Consider a discrete distribution for the yield γ as follows: For $0 \le \gamma_1 \le \gamma_2 \le \ldots \le \gamma_N$,

$$\gamma = \begin{cases} \gamma_1, & \text{w.p. } \theta_1; \\ \gamma_2, & \text{w.p. } \theta_2; \\ \vdots & \\ \gamma_N, & \text{w.p. } \theta_N. \end{cases} ; \quad \sum_{i \in [n]} \theta_i = 1$$

We solve for the equilibrium $p_m^{\mathsf{NI}}(\gamma_i)$, $i \in \{1, 2, \ldots, N\}$, where:

$$\text{for each } i \in \{1, 2, \ldots, N\}\text{: } M\left(1 - p_m(\gamma_i)\right) + kM \min\left\{\frac{b}{p_m(\gamma_i)}, 1 - p_m(\gamma_i)\right\} = \frac{n}{2\alpha}\left(\sum_i \theta_i \gamma_i p_m(\gamma_i)\right).$$

The simulation procedure under DBT is identical to NI except that b is replaced by $b + \beta$, where $\beta = \frac{B}{kM}$. Under the GSP scheme, we identify the equilibrium p_g for a given choice of δ_W.

Algorithm 1: Equilibrium Outcome Under NI

Data: M, k, n, b, α, $G=(\gamma_1, \gamma_2, \ldots, \gamma_N)$, $\Theta=(\theta_1, \theta_2, \ldots, \theta_N)$

Function *effort*

  Input: $\hat{\mathbf{p}}_m(\gamma)$

  Output: q_e

  $q_e \leftarrow \frac{1}{2\alpha} \times$ `SumProduct`$(\hat{\mathbf{p}}_m(\gamma), \Theta, G)$ /* $q_e^* = \frac{\mathbb{E}_\gamma[\hat{p}_m(\gamma)\gamma]}{2\alpha}$ from (9) */

  return q_e

end

Function *demand*

  Input: p

  Output: D

  $D \leftarrow M(1-p) + kM \min\left\{\frac{b}{p}, 1-p\right\}$ /* $D(p_m)$ from LHS of (5) */

  return D

end

Function *market-price*

  Input : $\mathcal{Q}$

  Output: $\mathbf{p}_m(\gamma)$

  forall $\gamma \in G$ **do**

    $p_m(\gamma) \leftarrow$ `Unitroot` of `demand`(p) $= \mathcal{Q}\gamma$. /* p_m solves (10) */

  end

  return $\mathbf{p}_m(\gamma)$

end

Function *equilibrium*

  Output: q_e^{NI}

  $\mathbf{p}_m(\gamma) \leftarrow \text{repeat}(0, N)$ /* Assign arbitrary values to $\mathbf{p}_m(\gamma)$ */

  repeat

    $\hat{\mathbf{p}}_m(\gamma) \leftarrow \mathbf{p}_m(\gamma)$

    $q \leftarrow$ `effort`$(\hat{\mathbf{p}}_m(\gamma))$

    $\mathcal{Q} \leftarrow nq$ /* All farmers exert the same effort */

    $\mathbf{p}_m(\gamma) \leftarrow$ `market-price`$(\mathcal{Q})$

  until $||\hat{p}_m(\gamma) - p_m(\gamma)|| \leq \epsilon$;

  return `effort`$(\mathbf{p}_m(\gamma))$

end

Algorithm 2: Equilibrium Outcome Under GSP

Data: M, k, n, b, B, α, η, δ_W, $G=\{\gamma_1, \gamma_2, \ldots, \gamma_N\}$, $\Theta=\{\theta_1, \theta_2, \ldots, \theta_N\}$

$\mathcal{P}_g \leftarrow$ seq(start $=0$, end $=1$, by $=\epsilon$) `/*` $\mathcal{P}_g$ `is the set of prices we search over to identify the equilibrium support price */`

Function *`surplus`*

  Input : p_g

  Output: Π_S

  $\mathbf{p}_m(\gamma) \leftarrow$ repeat$(0,\, N)$ `/* Assign arbitrary values to` $\mathbf{p}_m(\gamma)$ `*/`

  repeat

    $\hat{\mathbf{p}}_m(\gamma) \leftarrow \mathbf{p}_m(\gamma)$

    `/*` q_e^* `solves` $q_e = \frac{\mathbb{E}[\hat{p}_m(\gamma)\gamma]+\mathbb{E}\left[(p_g-\hat{p}_m(\gamma))\gamma 1\left(p_g>p_m(\gamma), \gamma q_e<\frac{B}{np_g}\right)\right]}{2\alpha}$ `*/`

    $q_e \leftarrow$ `FixedPoint` of $\frac{1}{2\alpha}\times$ $\Big($`SumProduct`$(\hat{\mathbf{p}}_m(\gamma), \Theta, G)+$`SumProduct`$((p_g-\mathbf{p}_m(\gamma)), \mathbf{1}(p_g>\mathbf{p}_m(\gamma)), \gamma q_e<\frac{B}{np_g}), G, \Theta\Big)$

    $\mathcal{Q} \leftarrow nq_e$

    forall γ *in* G **do**

      if $p_g >$ *`market-price`*$\left(\mathcal{Q}\gamma - \min\left\{\mathcal{Q}\gamma, \frac{B}{p_g}\right\}, (1-\delta_W)\frac{\min\left\{\mathcal{Q}\gamma, \frac{B}{p_g}\right\}}{kM}\right)$ **then**

        `/* If` $p_g > p_m(\gamma)$ `*/`

        $p_m(\gamma) \leftarrow$`market-price`$\left(\mathcal{Q}\gamma - \min\left\{\mathcal{Q}\gamma, \frac{B}{p_g}\right\}, (1-\delta_W)\frac{\min\left\{\mathcal{Q}\gamma, \frac{B}{p_g}\right\}}{kM}\right)$

        $q_g, q_m \leftarrow \min\left\{\gamma q_e, \frac{B}{np_g}\right\}, \gamma q_e - q_g$

      else if $p_g <$*`market-price`*$(\mathcal{Q}\gamma, 0)$ **then**

        `/* If` $p_g < p_m(\gamma)$ `*/`

        $p_m(\gamma) \leftarrow$ `market-price`$(\mathcal{Q}\gamma, 0)$

        $q_g, q_m \leftarrow 0, \gamma q_e$

      else

        `/* If` $p_g = p_m(\gamma)$ `*/`

        $p_m(\gamma) \leftarrow p_g$

        $q_g, q_m \leftarrow$ `UnitRoot` of `demand`$(p_g,\ (1-\delta_W)\frac{n}{kM}q_g) = \mathcal{Q}\gamma - nq_g, q_e\gamma - q_g$

      end

    end

  until $||\hat{\mathbf{p}}_m(\gamma) - \mathbf{p}_m(\gamma)|| \leq \epsilon$;

  forall γ *in* G **do**

    $u_C^{APL}(\gamma) \leftarrow$ `Integrate`$(1-x,\ 0,\ 1-p_m(\gamma))$ `/*` u_C^{APL} `from (1) */`

    $u_C^{BPL}(\gamma) \leftarrow$ `Integrate`$(1-x,\ 0,\ \min\left\{\frac{b}{p_m(\gamma)}, 1-p_m(\gamma)-\frac{n}{kM}q_g\right\})$

    `/*` u_C^{BPL} `from (3) */`

  end

  $\Pi_S \leftarrow Mw_{APL} + kMb + B - n\alpha q_e^2 +$ `SumProduct`$(G, Mu_C^{APL}(\gamma) + kMu_C^{BPL}(\gamma))$

  `/*` Π_S `from (7) */`

  return Π_S

end

```
Function demand
    Input  : p, q_S
    Output: D
    D ← M(1 − p) + kM min{ b/p, 1 − p − q_S }
    return D
end
Function market-price
    Input  : S, q_S
    Output: p_m
    p_m ← Unitroot of demand(p, q_S) = S.
    return p_m
end
Function equilibrium
    Output: p_g^*
    forall p_g in 𝒫_g do
        Π_S(p_g) ← surplus(p_g)
    end
    p_g^* ← which.max(Π_S(p_g)) for p_g in 𝒫_g.          /* p_g^* = arg max_{p_g ∈ 𝒫_g} Π_S(p_g) */
    return p_g^*
end
```