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Socially Beneficial Rationality: The Value of Strategic Farmers, Social Entrepreneurs, and For-Profit Firms in Crop Planting Decisions

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Abstract. The price fluctuation in agricultural markets is an obstacle to poverty reduction for small-scale farmers in developing countries. We build a microfoundation to study how farmers with heterogeneous production costs, under price fluctuations, make crop-planting decisions over time to maximize their individual welfare. We consider both strategic farmers, who rationally anticipate the near-future price as a basis for making planting decisions, and naïve farmers, who shortsightedly react to the most recent crop price. The latter behavior may cause recurring overproduction or underproduction, which leads to price fluctuations. We find it important to cultivate a sufficient number of strategic farmers because their self-interested behavior alone, made possible by sufficient market information, can reduce price volatility and improve *total* social welfare. In the absence of strategic farmers, a well-designed preseason buyout contract, offered by a social entrepreneur or a for-profit firm to a *fraction* of contract farmers, brings benefit to farmers as well as to the firm itself. More strikingly, the contract not only equalizes the individual welfare in the long run among farmers of the same production cost, but it also reduces individual welfare disparity over time among farmers with heterogeneous costs regardless of whether they are contract farmers or not. On the other hand, a nonsocially optimal buyout contract may reflect a social entrepreneur's over-subsidy tendency or a for-profit firm's speculative incentive to mitigate but not eliminate the market price fluctuation, both preventing farmers from achieving the most welfare.

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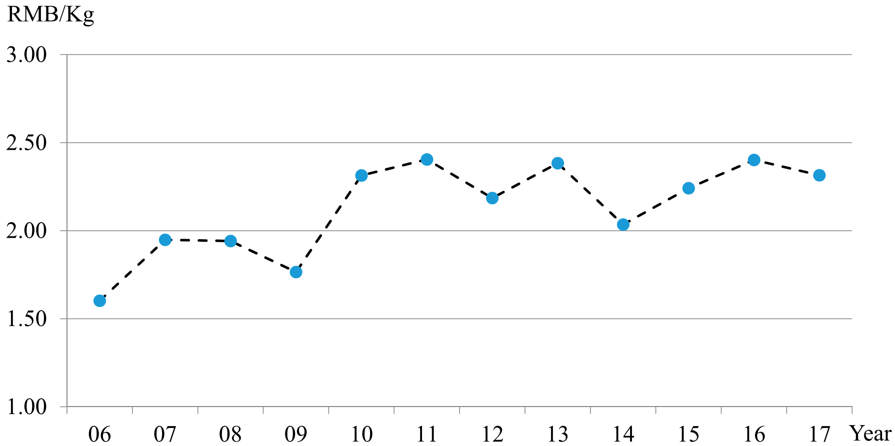
1. Introduction

In developing countries, small-scale farmers are among the poorest, and they are faced with considerable earning uncertainty. One of the main obstacles to poverty reduction for them is the price fluctuation in agricultural markets. In China, for example, farmers who plant fruit or vegetables (such as watermelon, oranges, loquat, gourds, cabbage, etc.) often go bankrupt after a rich harvest because prices are slashed in local markets (Feng 2014), and in India, small local onion and potato growers suffered a more than 50% price drop from 2015 to 2016 (Buradikatti 2016, Sharma 2016). In fact, dramatic price fluctuations, far from being rare, are widely observed in agricultural markets. According to a report published jointly by a number of international organizations, such as the Food and Agriculture Organization, World Bank, and World Trade Organization, agricultural markets are *intrinsically* subject to greater price variation than other markets (FAO et al. 2011). From 1983 to 1997, the market prices for Robusta coffee beans fluctuated by 40% to 195% of the average (Brown et al. 2008), and the prices of watermelon in local Chinese markets (see Figure 1) show evidence of strong cyclic annual price swings. As the price fluctuation is a significant obstacle to welfare improvement of small-scale farmers, in this paper we study strategies, operated by individuals or institutions, that can stabilize prices and increase small-scale farmers' welfare.

The explanation of perpetual market price fluctuations in the agricultural market has been developed since the celebrated, macroeconomic, cobweb theorem (Ezekiel 1938). That is, the production is determined by the farmers' response to the price, and farmers often

Figure 1. (Color online) Watermelon Price Fluctuation



Source. Data from WIND Database (www.wind.com.cn).
Notes. Average selling price of watermelon in the third and fourth quarter in China from 2006 to 2017. The prices are discounted by average inflation rate.

make shortsighted crop-planting decisions based on the relatively easily obtained prices of the previous season or blindly do what other farmers are doing (the latter action even further amplifies that irrationality). Bariyo (2014) reported farmers' back-and-forth decisions to abandon and then resume coffee cultivation on the basis of the latest market prices. Making crop-planting decisions in such a way is easy for farmers and seems logical to them, but it ignores the impact on the crop supply and the resulting market price and, therefore, often leads to price fluctuations. Here are two recent examples that manifest this cobweb phenomenon:

Example 1. The unprecedented high market price of apples before 2015 induced some farmers in China to expand their planting areas. The resulting overproduction led to fierce market competition and a significant price drop in 2015 (China National Radio 2015).

Example 2. The high prices of other staples have encouraged many small farmers in Brazil to stop planting beans, which led to the bean shortage that has sent bean prices skyrocketing in 2016 (Parkin and Lewis 2016).

In both examples, farmers who follow the latest market price suffer a welfare loss later because of the overproduction of the crops they plant, and they miss the chance to plant other crops that would have been more profitable. The extant literature on the cobweb phenomenon often takes the supply-and-demand curves as exogenously given. However, these curves are determined by farmers' individual incentives and planting decisions. To study welfare-improving mechanisms, we start with the individual farmer's utility maximization problem. We first show how farmers' (involuntarily) shortsighted behavior leads to a recurring boom and bust, which provides a microfoundation for the cobweb phenomenon. Then we further study sustainable and incentive-compatible mechanisms that are applied to a fraction of farmers but can increase farmers' total welfare.

The recurring slashing of prices and loss in farmers' welfare are attributed largely to farmers' difficulty in obtaining market information, predicting future prices, and assessing the effect of their planting decisions on themselves. There have been repeated efforts by governments, firms, and nongovernmental organizations (NGOs) to prevent farmers from behaving shortsightedly. For instance, governments, NGOs, and business sectors adopt information and communication technology to help disseminate information, such as historical and current market prices, weather information, and advisories about near-future market prices, to farmers (see examples in Chen and Tang 2015). The effectiveness of such practices is unclear. This is because not all farmers can obtain or process the market information, partly because of the limited access to education in developing countries (Epstein and Yuthas 2012). It is very likely that only a small fraction of farmers are able to use the market information to predict the near-future market prices and make planting decisions that maximize their individual welfare. Because the farmers who can do so are self-serving, it is not clear whether their decisions also improve the welfare of the other farmers or make it even worse.

We begin our analysis by building a stylized multiperiod model that captures the involuntarily irrational behavior of some farmers who base their planting decisions on the previous season's market price. Building on this model, we study the impact of those self-serving, forward-looking farmers, referred to as *strategic* farmers, on the welfare of the other farmers who are shortsighted, referred to as *naïve* farmers. We find that the strategic farmers' ability to predict the near-future market price can help stabilize the market price, thereby benefiting farmers who have no production cost advantage. This implies that the strategic farmers' forward-looking behavior can be both self-serving and socially beneficial. On the other hand, we show that the benefits are greatly discounted when the number of strategic farmers is small or when naïve farmers have limited savings and would exit farming permanently because of bankruptcy. Therefore, it is imperative to explore other solutions.

Contract farming is another way to offer farmers a guaranteed market outlet and reduce their welfare uncertainty. There is a preseason procurement contract between the farmers and the buyer with a specific procurement price and date for near-future transactions. In practice, most of the contract-farming projects are initiated by social entrepreneurs (SEs) and for-profit firms. For instance, Starbucks has contract-farming agreements with local farmers who plant coffee beans in Thailand and Indonesia (Rungfapaisarn 2013). Unlike government and NGOs who give free aid to the poor, for-profit firms have profit-making goals, and SEs balance social objectives and for-profit goals. It is reported that many SEs in the agricultural business expect the procurement contracts to fight poverty and guarantee a reliable supply of agricultural products (Fraser 2012). For an SE, we are interested in identifying a contract that both improves farmers' welfare and brings enough profit to sustain its own operations. For a profit-driven firm, we focus on a setting in which the goal of profit maximization is compatible with improving farmers' welfare.

Specifically, building on the microfoundation of farmers' utility maximization, we study farming contracts between farmers with heterogeneous production costs and a firm (SE or profit-driven enterprise) that offers a stable procurement price to a fraction of farmers. We find that implementing a well-designed buyout contract can help to alleviate the price fluctuation and bring benefits to both farmers and the SE. This stable price depends on the potential market size and farmers' production costs. A lower price (i.e., insufficient subsidy) does not alleviate the market fluctuation, and a higher price (i.e., over-subsidy) distorts the market incentive and hurts both the firm and some farmers. Moreover, we find that the optimal contract not only equalizes the individual welfare in the long run among farmers of the same production cost, but it also reduces individual welfare disparity over time among farmers with heterogeneous costs regardless of whether they are contract farmers or not. This finding highlights the additional benefit of the win–win contract in creating *fairness* in these regards. In making an extension of the single price contract to time-varying procurement prices, we show that the prices in the optimal time-varying contracts converge to the same unique price.

The contract design for a for-profit firm, however, is more subtle. In a setting in which a for-profit firm has to pay a high price to source from an external market if not satisfied by contract farmers and the local market, the aforementioned optimally designed contract for the SE also increases the for-profit firm's profit and meanwhile improves farmers' welfare. But it does not always maximize the firm's profit. It is likely that the for-profit firm has a speculative incentive to mitigate but not completely eliminate the market price fluctuation. In such a case, the for-profit firm alternates sourcing between contract farmers and the local market to enjoy the most cost efficiency, preventing farmers from achieving their most welfare. Therefore, regulation on for-profit firms may be needed.

This paper contributes to the literature that addresses the challenges of reducing agricultural market fluctuations and improving farmers' welfare in developing economies. Specifically, we first build a microfoundation of farmers' utility maximization, which enables a detailed welfare analysis. Second, with the microfoundation, we study interactions among farmers with heterogeneous production costs in jointly determining the crop's price, which, in turn, affects their welfare. We show that self-interested behavior by individual farmers can be socially beneficial. Third, we design procurement contracts for social entrepreneurs or profit-driven firms that are offered to a fraction of farmers and are win–win for both the organization and farmers. In sum, our results demonstrate that self-interested behavior by individual farmers, social entrepreneurs, or profit-driven firms can be socially beneficial at the same time, improving the *total* social welfare with carefully disclosed information or optimally designed contracts offered to a *fraction* of farmers.

2. Literature Review

Our paper is closely related to the works on the cobweb phenomenon in the macroeconomics and agronomics literature. Ezekiel (1938) first attributes the phenomenon (recurring cyclical herding in production) to the fact that producers often base their short-run production plans on the assumption that the present prices will continue. Our paper differs from that literature in three ways. First, our goal is to illustrate that the self-interested behavior of strategic farmers, social entrepreneurs, and for-profit firms can reduce the price fluctuations, whereas the focus of the cobweb theory is to explain the price oscillations observed in various markets. Notably, we take the perspective that such price oscillations can be mitigated by carefully designed, incentive-compatible mechanisms.

Second, one key feature of our model is that we build a microfoundation of an individual farmer utility model with heterogeneous production costs, such that the supply curve is derived from farmers' utility maximization rather than being exogenously assumed as it is in the cobweb models. With such a utility-based model, we can also evaluate each individual farmer's welfare. For example, we show that a carefully designed contract offered to a fraction of farmers benefits all stakeholders and, at the same time, reduces individual welfare disparity among farmers.

Third, the cobweb models lead to the discussion about the rational expectations assumption and its validity for *all* farmers (see, e.g., Nerlove 1958). This assumption is often made in the operations literature on strategic consumers (see, e.g., Su 2010 and Cachon and Swinney 2011 and references therein). We consider a fraction of farmers who have rational expectations or who contract with social entrepreneurs or for-profit firms. This feature emphasizes interactions via the market prices among farmers who have different rationality or access to external farming contracts. In a different context but a similar spirit, Su (2010) and Cachon and Swinney (2009) consider the interactions between myopic and forward-looking customers, and Hu et al. (2017) consider the interactions among customers who have different granularity of information about the service-system congestion. The latter shows that, in the presence of information cost, a fraction of customers may intentionally ignore the real-time information, thereby benefiting social welfare. Aflaki et al. (2015) find that, in the presence of hassle cost, a fraction of forward-looking customers may intentionally choose not to search for more information, and this rational ignorant behavior may benefit the society as well.

We also contribute to the economics and operations management literature on "social herding," as our model captures the farmers' shortsighted herding behavior in planting or abandoning crops. Veeraraghavan and Debo (2009) identify the herding effect in queues in which consumers infer service quality from the length of the queue. In our model, herding is an outcome of farmers' shortsighted reactions to recent prices, and we study the role of self-serving strategic farmers and firms in alleviating herding in crop planting. We provide a solution under which the herding effect can be eliminated by offering a carefully designed contract, which benefits both farmers and firms. More broadly, this paper is related to the emerging literature on social operations management, which focuses on how social interactions leading to collective social behaviors (in this paper, individual farmers' planting decisions collectively determine the total production quantity and market price) have an impact on firms' operational decisions (in this paper, procurement) and how operational decisions (in this paper, contract farming) can influence the formation of collective social behaviors.

Our study also links to the literature showing that a lack of information can lead to *endogenized uncertainty* in business practices. For example, the well-known "bullwhip effect" (see Lee et al. 1997) shows that the lack of information about true customer demand causes the variance of order quantities to increase as one moves upstream along the supply chain. Hu et al. (2015) show that sales uncertainty can occur when customers are socially influenced by others when making purchasing decisions. Cooper et al. (2006) show that incorrect beliefs about customer behavior cause a spiral-down effect; that is, revenues systematically decrease over time. In contrast, we focus on investigating win–win mechanisms that can be implemented by informed individuals, a social entrepreneur or a for-profit firm, to reduce the negative effects of the lack of market information.

Poverty alleviation in developing countries has been studied in the burgeoning operations management literature that focuses on the design of socially responsible operations (see Sodhi and Tang 2014 for a comprehensive review). Many of those studies explore the value of disclosing market information in helping farmers improve their welfare. For instance, Chen et al. (2013) study Indian conglomerate ITC's new business model in which the firm helps farmers to obtain various information through the E-Choupals network and allows farmers to sell directly to the firm. Chen and Tang (2015) examine the value of both private and public signals of the agricultural market. Chen et al. (2015) investigate the incentives for knowledge sharing among competing farmers. Tang et al. (2015) examine whether, under a Cournot competition, farmers should utilize market information to optimize their production plans when both the market potential and the process yield are uncertain. Belloni et al. (2016) show that a monopsonistic buyer (a downstream principal in general) with private demand information can contract with segmented farmers (upstream agents) to restore the first-best productive efficiency. Our paper differs from those papers in that we focus on the scenario in which the market information is not available to all the farmers. We consider some farmers who can only react shortsightedly to the market and study how these farmers' welfare is affected by self-serving strategic farmers and firms. By modeling farmers' *dynamic* crop-planting decisions over time, we find that the self-serving individuals and firms can also be beneficial to some shortsighted farmers and improve the total social welfare. In terms of methodology, we adopt a multiperiod model with interactions both within and across periods, whereas all the aforementioned papers build a one-period model.

Finally, our paper is also related to the literature on price protection mechanisms in agricultural markets. Nicholls and Opal (2005) review price protection implemented through fair trade operations and study its effectiveness. Haight (2011) suggests that a fair-trade certification model, which guarantees a fixed price if the farmers meet high production standards, can be poorly implemented and only applied to limited types of crops (Fair Trade USA 2012). Annan and Schlenker (2015) study the effectiveness of federal crop insurance in the United States. They argue that this government program may be a disincentive for farmers to adapt to extreme weather. Most of these papers are empirical studies. In our paper, we develop an analytical model to study the effectiveness of a preseason procurement contract, offered by an SE or a for-profit firm, in reducing market fluctuation and improving farmers' welfare. We identify many potential risks associated with the contract and find that a careful design is crucial to the effectiveness of such a contract.

3. Model

We study a multiperiod model in which farmers make planting decisions for a single crop in each period over an infinite horizon. The individual farmers are infinitesimally small scale, and the size of the farmer population is normalized to one. At the beginning of the period t, each farmer observes p_{t-1}, the crop's market price at the end of the previous period $t-1$, and decides whether to cultivate the crop in the current period t. The planting decision depends on each farmer's individual assessment of the near-future crop price and the cost of planting the crop. The crop production takes one full period. At the end of the period, all of the harvested crop is sold to the market with the price p_t determined by the total output from all farmers.

Farmers are heterogeneous in their capability of assessing crop prices. We assume a fraction, α, of the farmers is strategic and the remainder is naïve. Specifically, the strategic farmers have *full information* about the market and can make a *rational expectation* of the near-future market price p_t, but naïve farmers are incapable of correctly predicting the market price, and they simply take p_{t-1} from the last period as the indicator of the near-future price at the end of period t.

In addition, farmers also have heterogeneous endowment of production costs, denoted as c, which is uniformly distributed on $[0, \bar{c}]$ capturing the idiosyncratic production capabilities among farmers. Let F denote the cumulative distribution function (c.d.f.) of production cost c. We model a farmer's perceived utility of planting the crop as the farmer's individual assessed market price minus its production cost. That is, a strategic farmer's perceived utility, denoted by u_t^s, and a naïve farmer's perceived utility, denoted by u_t^n, are

$$u_t^s = p_t - c, \quad u_t^n = p_{t-1} - c, \tag{1}$$

respectively. We focus on small-scale farmers and premise that farmers are unlikely to collaborate to make joint production decisions given their heterogeneity along the two dimensions as just mentioned. In the beginning of each period, a farmer chooses to cultivate the crop if and only if the farmer's perceived utility is no less than zero. Our model could accommodate the heterogeneity in farmers' outside options as well by interpreting c as a general cost, including farmers' opportunity cost of farming. For instance, c could represent the heterogeneous earning farmers would have received if they left their land and traveled to a city to become migrant workers. Moreover, we extend our model by considering endogenized outside options, the values of which are based on the farmers' individual perceived utility of planting other crops (see Section 6.1).

As farmers are infinitesimal and the size of the farmer population is scaled to one, the total amount of crop produced by all strategic farmers and naïve farmers in period t, denoted by q_t^s and q_t^n, are

$$\begin{aligned} q_t^s &= \alpha \mathsf{P}(u_t^s \geq 0) = \alpha F(p_t), \\ q_t^n &= (1-\alpha)\mathsf{P}(u_t^n \geq 0) = (1-\alpha)F(p_{t-1}). \end{aligned} \tag{2}$$

As observed in many developing countries, it is not economical for small-scale farmers to store or transport their crops, especially perishable crops, to distant markets. Thus, in our model, we assume all the crop is sold to a market that all the farmers have access to. We use a deterministic model to study how to influence farmers' shortsighted behavior, leaving aside the uncontrollable yield uncertainty, which is taken into account in Section 6.2. Let Ω denote the potential market size. As farmers sell the homogeneous crop, the market would be cleared at a market-clearing price associated with the total production quantity:

$$\begin{aligned} p_t &= \Omega - bq_t = \Omega - b(q_t^s + q_t^n) \\ &= \Omega - b[\alpha F(p_t) + (1-\alpha)F(p_{t-1})], \end{aligned} \tag{3}$$

where $b > 0$ measures how the market price is sensitive to the production quantity and, in particular, every unit increase in the total supply quantity would lead the market price to drop by \$$b$. The larger the value of b, the more sensitive the market price to the production quantity. Note that p_t appears in both sides of this equality, implying that the strategic farmers rationally anticipate the future price when making planting decisions. Equations (1)–(3) indicate that farmers interact indirectly with one another through the market price. That is, the collection of all individual farmers' planting decisions determines the market price, which, in turn, affects the realized utility of each one of them. For ease of exposition, we make the following assumptions throughout the paper:

Assumption 1 (Diversity in Planting Decisions). $\bar{c} \le \Omega \le b + \bar{c}$.

Assumption 1 rules out some trivial cases: $\Omega \ge \bar{c}$ avoids the situation in which some farmers will never plant the crops regardless of the market price; $\Omega - b \le \bar{c}$ eliminates that all farmers will plant crops even at the lowest possible market price.

Assumption 2 (Regular Initial Price). (a) $0 \le \Omega - b \le p_0 \le \Omega$, *and* (b) $p_0 \le \bar{c}$.

Assumption 2 regulates the initial market price. Assumption 2(a) is a natural assumption because $p_t = \Omega - bq_t$ and $0 \le q_t \le 1$ for $t \ge 1$. We could further narrow the range of p_0 as stated in Assumption 2(b) without loss of generality (WLOG). This is because (1) according to Equations (2) and (3), p_0 influences the farmers' crop production q_1 and market price p_1 only through $F(p_0)$, and (2) for any $p_0 > \bar{c}$, we have $F(p_0) = F(\bar{c}) = 1$ because $F(\cdot)$ is the c.d.f. with support on $[0, \bar{c}]$. Hence, any price beyond $\bar{c}$ is essentially equivalent to $\bar{c}$ in the sense that they have the same influence on the dynamics.

In what follows, we find the connection between farmers' naïve behavior and cyclical market fluctuations and examine the role of strategic farmers in influencing the farmers' planting decisions and the market prices. In Sections 4 and 5, we focus anew on social entrepreneurs and for-profit firms that self-interestedly induce naïve farmers not to make short-sighted decisions. Now we use Equations (1)–(3) to derive the market price evolution. Define

$$\bar{p} := \frac{\bar{c}}{\bar{c} + b}\Omega. \tag{4}$$

As we will see, without market interferences, the market price fluctuates around $\bar{p}$; that is, if $p_0 > \bar{p}$, then $p_1 < \bar{p}$ and vice versa. All our results in the rest would hold for a system with $p_0 > \bar{p}$ when the potential market interferences start from period 2. Hence, WLOG, we assume

Assumption 3 (WLOG). $p_0 < \bar{p}$.

In fact, Assumptions 1–3 can be combined into one: $\max\{0, \bar{c} - b\} \le \Omega - b \le p_0 \le \bar{p}$.

Proposition 1 (Market Dynamics). *Suppose Assumptions 1–3 hold. Denote* $g(\alpha) := \frac{b - \alpha b}{\bar{c} + \alpha b}$.

(i) (Convergence). *If* $g(\alpha) < 1$, *that is,* $\alpha > \frac{b - \bar{c}}{2b}$, *the market price process follows*

$$p_t = \bar{p} - g(\alpha)(p_{t-1} - \bar{p}) = \bar{p} + [-g(\alpha)]^t (p_0 - \bar{p}). \tag{5}$$

Then the market price process converges to $\bar{p}$; *that is,* $\lim_{t\to\infty} p_t = \bar{p}$.

(ii) (Divergence). *If* $g(\alpha) \ge 1$, *that is,* $\alpha \le \frac{b - \bar{c}}{2b}$, *the market price does not converge. In particular,*

(a) *If* $g(\alpha) = 1$, *that is,* $\alpha = \frac{b - \bar{c}}{2b}$, *the market price process alternates between two prices* $p_{2i-1} = 2\bar{p} - p_0$ *and* $p_{2i} = p_0 < p_{2i-1}$ *for any* $i \ge 1$, *which are centered at* $\bar{p}$.

(b) *If* $g(\alpha) > 1$, *that is,* $\alpha < \frac{b - \bar{c}}{2b}$, *there exists a threshold* $i' \ge 1$ *such that for* $t < 2i' - 1$ *the market price process diverges according to Equation (5), and for* $t \ge 2i' - 1$, *the process alternates between two constant prices* $p_{2i-1} = \Omega - b[\alpha + (1 - \alpha)\frac{p_{2i}}{\bar{c}}]$ *and* $p_{2i} = \bar{p} - g(\alpha)(\bar{c} - \bar{p}) < p_{2i-1}$ *for any* $i \ge i'$.

Proof. All proofs can be found in an online appendix. Specifically, the proof of Proposition 1 can be found in Online Appendix E. □

Proposition 1 implies that $p_t - \bar{p} = -g(\alpha)(p_{t-1} - \bar{p})$ alternates between positive and negative values over time, and its absolute value $|p_t - \bar{p}|$ decreases if $g(\alpha) < 1$ and (weakly) increases if $g(\alpha) \ge 1$. Thus, if $g(\alpha) < 1$, regardless of the initial price point, p_t converges to $\bar{p}$, which we call the *limiting market price*. On the contrary, if $g(\alpha) = 1$, the price process alternates between two constant prices; if $g(\alpha) > 1$, the process first diverges until a time point $2i' - 1$, after which it alternates between two constant prices, which corresponds to the scenario in which all naïve farmers flood to plant in even periods and only some of them do so in odd periods. Overall, compared with the price fluctuation when $g(\alpha) = 1$, the price oscillates more significantly when $g(\alpha) > 1$. Notably, we find that even if we allow each farmer's crop quantity to be a continuous variable, denoted by $q \in [0, 1]$, as opposed to discrete choices $q \in \{0, 1\}$ in the current model, each farmer would choose either $q = 1$ if the farmer's individual perceived utility defined by Equation (1) is nonnegative or $q = 0$ otherwise (see Online Appendix A). Thus, the market evolution pattern remains the same as that described in Proposition 1.

In view of Proposition 1, the size of the strategic farmers α plays a significant role in stabilizing the market price.

Corollary 1. *Suppose Assumptions 1–3 hold. If* $\alpha > \frac{1}{2}$, *the market price process always converges. When* $\alpha = 0$, *the market price process converges if and only if* $b < \bar{c}$.

Note that $g(\alpha) = \frac{b - \alpha b}{\bar{c} + \alpha b} \ge 0$ decreases in the fraction of strategic farmers α. Corollary 1 shows that if there exists a sufficiently large fraction of strategic farmers (i.e., $\alpha > \frac{1}{2}$), the market price process always converges; that is, $g(\alpha) < 1$. However, in the absence of strategic farmers (or other forms of interference), the market price process converges naturally if and only if $b < \bar{c}$, that is, when the market price is not sensitive to the total supply. In that situation, the market can achieve self-healing, and no external help is needed to ensure long-term stability. Therefore, we choose to omit this relatively simple case for expositional brevity by imposing the following assumption throughout the rest paper. Nevertheless, most of the analysis can be generalized without this assumption.

Assumption 4 (Divergence by Default). $b \geq \bar{c}$.

More importantly, our model provides a microfoundation of farmers' utility maximization for the boom-and-bust cobweb phenomenon (see Ezekiel 1938): when the price realized at the end of a period is high, a large number of naïve farmers flood to plant the crop in the upcoming period because they think the price will continue to be high. This results in crop overproduction and a price drop in the following period. Similarly, when the price realized at the end of a period is low, some naïve farmers choose to abandon planting the crop (they may plant another crop, see Section 6.1, or seek other outside options, such as going to the city as migrant workers), thus leading to a supply shortage and a price rebound in the following period. The naïve farmers get trapped in the vicious cycle and suffer from the price fluctuations caused by the recurring underproduction or overproduction. This unfavorable situation is persistent when there is a lack of sufficient strategic farmers, that is, $\alpha \leq \frac{b-\bar{c}}{2b}$ (equivalently, $g(\alpha) \geq 1$), and is also manifested in the following farmers' welfare analysis.

A farmer's individual welfare in period t is defined as the market price realized at the end of that period minus the farmer's production cost, that is, $p_t - c$, if the farmer plants the crop in period t and zero otherwise. Let *market cycle i* represent a pair of consecutive periods $2i-1$ and $2i$. We call a farmer's average welfare in cycle i the farmer's *short-term welfare* in that cycle. We first analyze an individual naïve farmer's average welfare when the fraction of strategic farmers is relatively small; that is, $g(\alpha) \geq 1$. By Proposition 1, there exists i' such that the market price process alternates between two fixed prices for cycle $i \geq i'$. For brevity, our analysis of the farmer's welfare focuses on periods after cycle i'. Denote by $w^n(c)$ and $w^s(c)$ the average welfare of a naïve farmer and a strategic farmer, respectively, with production cost c in any cycle $i \geq i'$.

Proposition 2 (Farmer Welfare in a Cyclic Market). *Suppose Assumptions 1–4 hold and $g(\alpha) \geq 1$. The market price process eventually fluctuates between two constant prices p_{2i-1} and p_{2i}. Consider those farmers who have a production cost c.*

(i) *If $c \leq p_{2i}$, both the naïve farmer and the strategic farmer plant the crop in all periods, and $w^n(c) = w^s(c) = \frac{1}{2}(p_{2i-1} + p_{2i}) - c > 0$;*

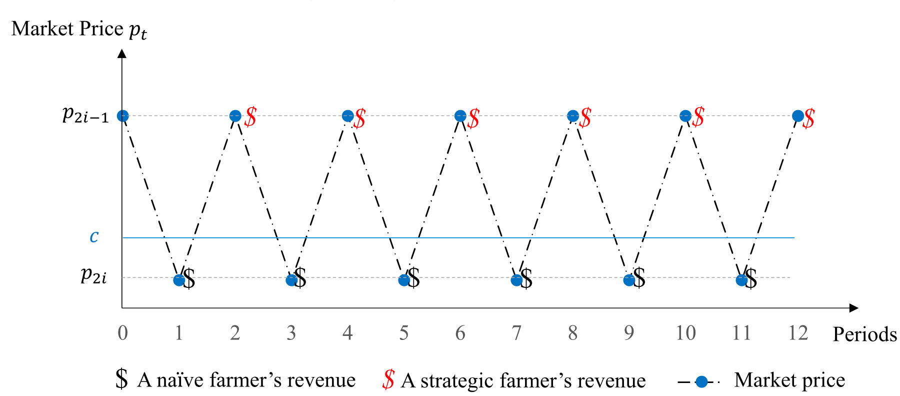
(ii) *If $p_{2i} < c \leq p_{2i-1}$, the naïve farmer plants the crop only in period $2i$ and $w^n(c) = \frac{1}{2}(p_{2i} - c) < 0$; the strategic farmer plants the crop only in period $2i-1$ and $w^s(c) = \frac{1}{2}(p_{2i-1} - c) \geq 0$;*

(iii) *If $p_{2i-1} < c$, neither the naïve farmer nor the strategic farmer plants the crop, and $w^n(c) = w^s(c) = 0$.*

The microfoundation enables a detailed welfare analysis for farmers under price fluctuations beyond the cobweb theory. Proposition 2 shows that the farmers' welfare depends on their production costs. When $g(\alpha) \geq 1$, only those naïve farmers who have extreme values of production costs would not be affected by the market fluctuation. Those low-cost naïve farmers plant the crop in all periods as their cost is always below the market price (i.e., $c \leq p_{2i}$), whereas those high-cost naïve farmers do not plant the crop in any period as their production cost always exceeds the market price (i.e., $c > p_{2i-1}$). Unfortunately, as Figure 2 illustrates, the naïve farmers who have intermediate cost levels (i.e., $p_{2i} < c \leq p_{2i-1}$) are hurt by the price fluctuation because of their naïve behavior, that is, planting the crop when the latest crop price is high and abandoning the crop when the price is low. Their individual welfare is negative as shown in Proposition 2(ii).

Unlike naïve farmers who have welfare loss because they unconsciously yet effectively herd in making

Figure 2. (Color online) Farmer's Revenue with $p_{2i} < c \leq p_{2i-1}$



Note. Naïve farmers with an intermediate cost level choose to plant the crop only in those odd periods that have realized prices below their production cost, leading to negative welfare, as shown in Proposition 2(ii).

planting decisions, strategic farmers can rationally anticipate the near-future market price, avoid herding with naïve farmers, and thus always receive nonnegative welfare.

The following proposition confirms that, when there is a sufficiently large fraction of strategic farmers (i.e., $g(\alpha) < 1$ or, equivalently, $\alpha > \frac{b-\bar{c}}{2b}$), their self-serving planting decisions always help stabilize market prices in the long run and may improve *all* farmers' welfare at the same time.

Proposition 3 (Socially Beneficial Rationality in a Converging Market). *Suppose Assumptions 1–4 hold and $g(\alpha) < 1$. Denote by p^n_{2i} the lower price in any cycle i when all farmers are naïve farmers.*

(i) *In the short run (i.e., in any given cycle i),* (a) *each strategic farmer obtains a (weakly) higher surplus than a naïve farmer with the same production cost;* (b) *those naïve farmers who have a production cost that is not too low, that is, $c > p^n_{2i-2}$, obtain a (weakly) higher surplus with strategic farmers than without; and* (c) *those naïve farmers who have a low production cost, that is, $c \le p^n_{2i-2}$, obtain a higher surplus with strategic farmers than without if $b = \bar{c}$ and a (weakly) higher or lower surplus if $b > \bar{c}$.*

(ii) *In the long run (i.e., in the limit as the cycle i approaches ∞),* (a) *each strategic farmer obtains the same surplus as the naïve farmer with the same production cost;* (b) *those naïve farmers who have a production cost that is not too low, that is, $c > \lim_{i\to\infty} p^n_{2i}$, obtain a (weakly) higher surplus with strategic farmers than without; and* (c) *those naïve farmers who have a low production cost, that is, $c \le \lim_{i\to\infty} p^n_{2i}$, obtain the same surplus with strategic farmers as without if $b = \bar{c}$ and a lower surplus with strategic farmers than without if $b > \bar{c}$.*

(iii) *In the long run, if* (a) *$b = \bar{c}$ or* (b) *$b > \bar{c}$ and*

$$\bar{p} - (\Omega - b) \ge \frac{2b\bar{c}(b-\bar{c})}{2b^2 + 3b\bar{c} - 2\bar{c}^2},$$

then the aggregate welfare of all farmers is higher with strategic farmers than without.

Proposition 3 shows that, in both the short and long runs, the strategic farmers' forward-looking behavior is indeed *rational* (parts ia and iia), and such rational behavior is also *socially beneficial* and helps increase the welfare of naïve farmers with not too low production cost (parts ib and iib). The welfare improvement for those naïve farmers, who are the victims of the price fluctuation, comes from the stabilized market price process because of the presence of strategic farmers.

The naïve farmers with very low production cost, however, might obtain *lower* but still positive welfare in the presence of strategic farmers when $b > \bar{c}$ (parts ic and iic). This is because these farmers plant in all periods, and the limiting market price $\bar{p}$ with strategic farmers could be lower than the average price when the market price process diverges (see Proposition 1(iib)). If this welfare decrease is relatively small in comparison with the welfare gain the other farmers obtain, the total welfare of all farmers can be improved by the presence of strategic farmers. We provide a sufficient condition for this result in part iii: the lowest possible market price $\Omega - b$ is sufficiently lower than the limiting price $\bar{p}$. This condition ensures that the population of farmers with very low costs (which is smaller than $\Omega - b$) is relatively small compared with the entire population, and as a result, the total welfare increases in the presence of strategic farmers.

Although there is benefit in being forward looking, cultivating a sufficient number of strategic farmers is still not easy. Farmers may lack the intrinsic reasoning ability or the external aids to obtain full market information and may, thus, fail to make fully rational decisions. In Online Appendix B, we discuss the impact of *backward-looking* strategic behavior on the market dynamics.

In addition, when the market price process converges, the fraction of strategic farmers α affects only the convergence rate and not the limiting market price. The larger the fraction of strategic farmers α is, the faster the market price process converges. However, before reaching the convergence, if a farmer's loss exceeds the farmer's savings, the farmer may go bankrupt and quit the farming business, which is considered in the rest of this section.

Proposition 4 (Impact of Bankruptcy). *Suppose Assumptions 1–4 hold and those farmers who exit the market because of bankruptcy never come back. Then the market price still converges, but the limiting market price is (weakly) higher than $\bar{p}$.*

Proposition 4 shows the impact of bankruptcy on the society: the collapse of farmers who would have survived with proper interference leads to a shortage of supply in the long run and, therefore, a limiting market price that is higher than $\bar{p}$. This situation may keep some less cost-efficient but strategic farmers in the market while eliminating some more cost-efficient but naïve farmers out of the market, and may lead to a socially suboptimal outcome.

In Online Appendix C, we detail the market dynamics and further present some numerical studies for this setting with possible bankruptcy. We find that the dynamics of the market price are more complicated when farmers' exit is incorporated. There are two forces that make the market price converge. One is the existence of strategic farmers who can predict the near-future price and alleviate naïve farmers' herding behavior. The other is farmers' exit, which reduces the number of naïve farmers and, thus, reduces the impact of their irrational behavior. These two forces are intertwined with each other, and it becomes technically challenging to explicitly track how many naïve farmers are left in the market in a given period, and thus, the price dynamics do not have a close-form expression. We numerically show that when the fraction of strategic farmers or the individual farmer's budget is not very small, the market price converges in a way that farmers who exit the market (if any) are almost or all high-cost farmers (whose cost is above $\bar{p}$) and the limiting market price is very close to or even the same as $\bar{p}$. In general, as stated in Proposition 4, the farmers' exit because of bankruptcy leads to a limiting market price that is higher than $\bar{p}$. In view of this potential negative impact of bankruptcy, it is imperative to examine other options that hold the potential to timely stabilize the market price and fairly distribute the benefits of price stabilization.

4. Social Entrepreneur

In the previous section, we showed that the conversion of a sufficient fraction of naïve farmers to strategic farmers would tilt the market dynamics from fluctuations to stabilization. However, one often observes that it is very difficult to cultivate enough strategic farmers for several reasons. First, in the case of fresh, local specialty fruits and vegetables, there is often a lack of extensive advisory systems that would help farmers obtain the market information about each crop and track the activities of other farmers. Second, farmers' limited ability to predict crop prices and their short-sighted behavior have remained major obstacles despite considerable advances in crop advisory communications. Third, external factors such as yield uncertainty may add significant complexity to the market-stabilizing efforts as we discuss in Section 6.2. For those reasons, in many developing countries where those problems are prevalent, it may not be as effective as it sounds to rely purely on farmers' forward-looking behavior to stabilize the market. One remedy can be market stabilization efforts by social organizations operating in a *sustainable* way.

In this section, we consider an SE who aims at improving the social welfare but also bears in mind sustaining the SE's own operations when naïve farmers do not voluntarily become strategic. The SE offers a fraction of farmers a preseason procurement contract that buys out all of their crop. We refer to this contract as a *buyout contract*. In this contract, the SE selects and announces a fixed buyout price p^o for *all* periods (see Online Appendix D.1 for time-varying buyout prices). At the beginning of each period, each farmer who is offered the contract decides whether to sign the contract with the SE. Farmers who accepted the SE's contract at the beginning of period t sell their crops to the SE at price p^o at the end of period t. Right after buying the crops from the farmers, the SE sells them in the market at the market price of that period, p_t. The preseason buyout contract we study here is different from the minimum-price support program offered by an NGO or the government in terms of the timing of the sales commitment. In the latter, the farmers contract with the NGO or government and can decide to sell their crop back to them when market prices fall below a prespecified level *after* the harvest, and our contract is agreed on *before* the season starts. The preseason contract can help guide the planting decisions in the first place, whereas the minimum-price support program may have a delayed effect. Although the minimum-price support program can also guarantee farmers' payoffs, it very likely comes at the cost of NGOs or governments, which may not be sustainable (see, e.g., Craymer 2016). Annan and Schlenker (2015) consider moral hazard issues in minimum-price support programs; that is, insurance protection reduces individual efforts in fighting against extreme weather conditions. We assume away such issues for the buyout program as we focus on the impact of the price guarantee on individual planting decisions. In the following subsection, we examine whether the aid from the SE would bring sustainable benefits to all farmers and to the SE as well.

4.1. Market Equilibrium in the Presence of an SE

We assume that all farmers are naïve and only an exogenous, α, fraction of farmers have access to the SE's contract. The limited access could be attributed to many factors. For instance, some farmers in rural areas may be too remote to be reached, and others may decline to work with an unfamiliar SE. We refer to farmers who are offered the SE's contract as *type-S* farmers and those who are not as *type-N* farmers. A type-S farmer's perceived utility, if the farmer accepts the contract and plants the crop, is $p^o - c$. Because the farmer would otherwise still behave naïvely and perceive utility $p_{t-1} - c$, the farmer will accept the contract only if the offered price p^o is strictly higher than the market price p_{t-1} in the last period. Hence, a type-S farmer's perceived utility in period t, denoted by u_t^o (where the superscript o emphasizes the buyout contract), is

$$u_t^o = \max\{p^o, p_{t-1}\} - c. \tag{6}$$

In other words, farmers are perceived to be incentive compatible in deciding whether to accept the buyout contract. The SE's buyout contract aims at stimulating farmers to plant crops in a period when the market price in the last period was low. We allow the contract to be evoked only contingently, which provides farmers with more flexibility than being locked in with the SE (in Online Appendix D.2, we study a contract that buys out a farmer's production in all periods). The corresponding quantity produced by type-S farmers, denoted by q_t^o, is

$$q_t^o = \alpha \mathsf{P}(u_t^o \geq 0). \tag{7}$$

The perceived utility of the remaining $1-\alpha$ fraction of type-N farmers, u_t^n, and their production quantity, q_t^n, remain the same as in Equations (1) and (2), respectively. The market clearing price in period t becomes

$$p_t(p^o; p_{t-1}) := \Omega - b(q_t^o + q_t^n) = \Omega - b\alpha F(\max\{p^o, p_{t-1}\}) - b(1-\alpha)F(p_{t-1}). \tag{8}$$

Note that $\Omega - b$ is the lowest market price, so no farmers would accept a contract with the buyout price below it. By the logic in Assumption 2(b), it is easily shown that p^o makes a difference only when it is smaller than $\bar{c}$. Hence, we make the following assumption.

Assumption 5. $\Omega - b \leq p^o \leq \bar{c}$.

We now study the long-term market trends for a certain level of buyout price p^o. According to Proposition 1 and Corollary 1, when $b \geq \bar{c}$ and there are neither strategic farmers nor any contract offered by the SE, the market price oscillates over time around the limiting market price $\bar{p}$. The SE's contract would stimulate planting the crop when the most recent market price is below p^o and, thus, reduce the price fluctuation. The following proposition shows that the extent to which the SE's buyout contract can help to reduce the price fluctuation varies, depending on the buyout price p^o and the fraction of contract farmers α.

Proposition 5. *Suppose Assumptions 1–5 hold. Denote* $\alpha_0 := 1 - \frac{(p^o-\bar{p})(\bar{c}+b)}{(p^o-p_0)b}$, $\alpha_1 := 1 - \frac{\bar{c}}{b}$ *and* $\alpha_2 := 1 - \frac{\bar{c}^2}{b^2}$.

(i) *Suppose* $p^o > \bar{p}$. (a) *If* $\alpha > \max\{\alpha_1, \min\{\alpha_0, \alpha_2\}\}$, *the market price process converges to* $\bar{p} - \frac{\alpha b(p^o-\bar{p})}{\bar{c}+(1-\alpha)b}$. (b) *If* $\alpha \leq \alpha_1$, *the price process does not converge.*

(ii) *Suppose* $p^o = \bar{p}$. *If* $\alpha > \alpha_2$, *the price process converges to* $\bar{p}$. *Otherwise, it does not converge.*

(iii) *Suppose* $p^o < \bar{p}$. *The price process does not converge.*

When the buyout price p^o is greater than the limiting market price $\bar{p}$, the market price process would converge if $\alpha > \max\{\alpha_1, \min\{\alpha_0, \alpha_2\}\}$, that is, there is a sufficient fraction of type-S farmers, and would diverge if $\alpha \leq \alpha_1$. In fact, numerical experiments show that there exists a threshold on α in the range $[\alpha_1, \max\{\alpha_1, \min\{\alpha_0, \alpha_2\}\}]$ such that when α is greater than that threshold the market price process converges to a value that is strictly less than $\bar{p}$, and when α is less than that threshold the process diverges. When p^o is exactly equal to $\bar{p}$, the threshold on α that determines whether the process converges is α_2. For a buyout price p^o that is below $\bar{p}$, the SE's contract does not stabilize the crop price. This is because, even if there is a large number of type-S farmers, by the time the market price fluctuates above p^o no farmers would accept the buyout contract, and thus, the contract is no longer effective and the price will not continue to converge. In such a situation, farmers are still exposed to significant price risks. When the buyout price is high (i.e., $p^o > \bar{p}$) and provided to a sufficient number of farmers, the SE incurs losses from the SE's operations in the long run because the limiting market price is strictly less than the buyout price $\bar{p}$. Even worse, in such a situation, some naïve farmers who are not offered the contract (i.e., type-N farmers) may find farming no longer profitable. In short, an inadequate subsidy (i.e., low buyout price) does not eliminate the fluctuations in the market price. Too large a subsidy (i.e., a high buyout price) is not desired, either, because it may create huge distortions in the market, forcing many noncontract farmers to give up farming, and result in losses for the SE.

The reason behind the market distortion when p^o is too high is that a higher buyout price induces more type-S farmers to produce the crop; more production leads to a lower market price and *crowds out* more type-N farmers who are not protected by the buyout contract. This unintended consequence is exemplified by many charitable programs whose generous subsidies undermine the efforts of those unsupported poor and, thus, may end up sustaining their poverty (see Miller 2014). This reveals that an SE's efforts, which are inspired by a desire to do good, do not necessarily result in a satisfactory outcome. A buyout price that is too high benefits contract farmers at the expense of noncontract farmers and may actually create more poverty. This also provides a caveat for governments and NGOs that may have more centralized power to offer subsidies, perhaps in the name of charity. Therefore, it is desirable to find the optimal design of the buyout contract.

4.2. Optimal Contract Design

As previously mentioned, the SE's goal is to improve farmers' welfare while sustaining the SE's own operations. The SE's profit in period t depends on the buyout price p^o and the market prices in periods $t-1$ and t. According to Equation (6), if $p^o > p_{t-1}$, then all type-S farmers with production cost $c < p^o$ accept the buyout contract. Thus, the SE buys crops from type-S farmers in period t at unit price p^o and then sells them at unit price p_t; thus, the SE's profit is $(p_t - p^o)q_t^o$. If $p^o \leq p_{t-1}$, then no type-S farmers accept the buyout contract in period t, and thus, the SE's profit in period t is zero. Formally, SE's profit in period t can be written as

$$\pi_t(p^o; p_{t-1}) := \begin{cases} (p_t - p^o)q_t^o & \text{if } p^o > p_{t-1}, \\ 0 & \text{otherwise.} \end{cases} \tag{9}$$

For a given p^o, let $\bar{w}_i^s(c)$ and $\bar{w}_i^n(c)$ denote the *average* welfare of, respectively, a type-S farmer and a type-N farmer with production cost c in cycle i. Specifically, we have

$$\bar{w}_i^s(c) = \frac{1}{2}\left\{\mathbf{1}_{\{u_{2i-1}^o \geq 0\}} w_{2i-1}^s + \mathbf{1}_{\{u_{2i}^o \geq 0\}} w_{2i}^s\right\} \text{ and}$$
$$\bar{w}_i^n(c) = \frac{1}{2}\left\{\mathbf{1}_{\{u_{2i-1}^n \geq 0\}} w_{2i-1}^n + \mathbf{1}_{\{u_{2i}^n \geq 0\}} w_{2i}^n\right\},$$

where

$$w_t^s = \begin{cases} p_t - c & \text{if } p^o \leq p_{t-1}, \\ p^o - c & \text{if } p^o > p_{t-1}, \end{cases}$$

and $w_t^n = p_t - c$ denote the welfare of, respectively, a type-S and a type-N farmer in period t if the farmer plants the crop, and $\mathbf{1}_{\{A\}}$ is an indicator function that equals one if condition A holds and zero otherwise. The indicator function is used to specify the criterion for planting the crop; that is, the perceived utility is nonnegative. We now focus on analyzing the impact of the buyout contract on farmers' welfare. See the proof of Proposition 6 in Online Appendix G for details about the farmers' welfare functions $\bar{w}_i^s(c)$ and $\bar{w}_i^n(c)$, which are functions of p_t in Equation (8) and p^o.

The SE's problem is to select the buyout price p^o that maximizes the total welfare of farmers in the long run while sustaining the SE's own operations (i.e., not incurring a loss in any period), which can be written as follows:

$$\max_{p^o} \int_0^{\bar{c}} \lim_{i\to\infty}\left(\alpha\bar{w}_i^s(c) + (1-\alpha)\bar{w}_i^n(c)\right)\frac{1}{\bar{c}}\,dc \qquad (10)$$
$$\text{s.t.} \quad \pi_t(p^o; p_{t-1}) \geq 0 \text{ for any } t.$$

We assume that the SE has access to a sufficient number of contract farmers in the remainder of this section.

Assumption 6. $\alpha > \alpha_2 = 1 - \frac{\bar{c}^2}{b^2}$.

If $b \leq \bar{c}$, Assumption 6 is innocuous. Moreover, Assumption 6 can admit a set of feasible buyout prices that stabilize the market (see Proposition 5). The same assumption is also used in Section 5 when a for-profit firm offers a buyout contract to farmers. In the following, we discuss the SE's profit and farmers' welfare. Define $\underline{c} = p_0$ for $b = \bar{c}$ and $\underline{c} = \Omega - b$ for $b > \bar{c}$.

Proposition 6 (Socially Beneficial Rationality of SE). *Suppose Assumptions 1–6 hold. If (1) $b = \bar{c}$ or (2) $b > \bar{c}$ and $\bar{p} - (\Omega - b) \geq \frac{2b\bar{c}(b-\bar{c})}{2b^2+3b\bar{c}-2\bar{c}^2}$, then $p^{o*} = \bar{p}$ is the unique optimal solution to SE's problem (10), under which the market price process converges to $\bar{p}$ and*

(i) *The SE receives a positive profit over any finite horizon, and the profit per market cycle diminishes to zero in the limit.*

(ii) *Compared with the surplus that farmers would receive in the absence of an SE,*

(a) *In the short run, both type-S and type-N farmers, with production cost $c > \underline{c}$, receive a (weakly) higher surplus in the presence of an SE. The type-S farmers with production cost $c \leq \underline{c}$ receive a lower surplus. The type-N farmers with production cost $c \leq \underline{c}$ receive the same amount of surplus if $b = \bar{c}$ and a lower surplus if $b > \bar{c}$.*

(b) *In the long run, both type-S and type-N farmers, with production cost $c > \underline{c}$, receive a (weakly) higher surplus because of the market stabilization in the presence of an SE. Both type-S and type-N farmers with production cost $c \leq \underline{c}$ receive the same amount of surplus if $b = \bar{c}$ and a lower surplus if $b > \bar{c}$.*

(c) *In the long run, the aggregate welfare of all farmers is higher with SE than without.*

Proposition 6 shows that a well-designed buyout contract can maximize the farmers' total welfare while keeping the SE's profit nonnegative for any period. As shown in Proposition 6(ii), when $b = \bar{c}$, at the individual level, both type-S and type-N farmers achieve certain welfare improvement in the long run because of the SE's contract; thus, by setting the buyout price at the optimal as $p^o = \bar{p}$, there could be a win–win–win situation for the SE, type-S, and type-N farmers. When $b > \bar{c}$, the welfare improvement is only attainable by farmers with relatively high cost $c > \underline{c}$, effectively *balancing* the individual welfare among farmers. The following corollaries present more detailed results on the virtues of this optimal buyout contract.

Corollary 2 (Balancing Welfare Among Farmers of the Same Cost). *Suppose Assumptions 1–6 hold and the SE sets the price at $p^o = \bar{p}$. Consider a farmer with production cost c. As i approaches ∞,*

(a) *if $c \leq \bar{p}$, the farmer plants crops in all periods, and $\lim_{i\to\infty}\bar{w}_i^s(c) = \lim_{i\to\infty}\bar{w}_i^n(c) = \bar{p} - c \geq 0$;*

(b) *if $\bar{p} < c$, the farmer does not plant the crop, and $\lim_{i\to\infty}\bar{w}_i^s(c) = \lim_{i\to\infty}\bar{w}_i^n(c) = 0$.*

In the limit, under the optimal buyout contract, the market price converges to $\bar{p}$ (see Proposition 5(ii)), which is the same as the buyout price itself. Thus, a farmer, regardless of the farmer's type, plants the crop in every period in the limit if the farmer's production cost is lower than $\bar{p}$ and otherwise does not plant in any period. Accordingly, as shown in Corollary 2, both type-S and type-N farmers receive identical utilities in the long run; that is, $\lim_{i\to\infty}\bar{w}_i^s(c) = \lim_{i\to\infty}\bar{w}_i^n(c)$.

Denote by $w_i^n(c)$ the average welfare of a naïve farmer with production cost c in any cycle i in the scenario without an SE and with all farmers being naïve. We find that the welfare improvement, that is, $\lim_{i\to\infty}\bar{w}_i^s(c) - w_i^n(c) = \lim_{i\to\infty}\bar{w}_i^n(c) - w_i^n(c)$, however, is not monotone in the farmer's cost endowment c. In *each* period, the optimal buyout contract $p^o = \bar{p}$ *reduces* the welfare gap between farmers who are at a cost advantage and who are at a cost disadvantage.

Corollary 3 (Fairness Across Classes of Farmers with Heterogeneous Costs). *Suppose Assumptions 1–6 hold and the SE sets the price at $p^o = \bar{p}$. There exists $i' \geq 1$ such that for any given pair of production costs c_1 and c_2 with $c_1 \leq p^n_{2i'} < c_2$, where $p^n_{2i'}$ is the market price without an SE, $\bar{w}^s_i(c_1) - \bar{w}^s_i(c_2) \leq \bar{w}^n_i(c_1) - \bar{w}^n_i(c_2) \leq w^n_i(c_1) - w^n_i(c_2)$ for all $i \geq i'$.*

Farmers with low production costs below $p_{2i'}$ have a cost advantage over those who have high production costs above $p_{2i'}$. As stated in Corollary 3, under the SE's optimal buyout contract, the welfare gap between those high- and low-cost farmers is smaller among type-S farmers than that among type-N farmers, which is further smaller than that among farmers in the scenario in which all farmers are naïve. Therefore, the SE helps not only improve the total welfare but also reduce the welfare gap between the advantaged and disadvantaged farmers. In sum, the distribution of benefits also tends to be balanced across farmers with *heterogeneous* production costs (see Corollary 3), in addition to the long-run individual welfare convergence among farmers with the *same* production cost, regardless of whether they are contract farmers or not (see Corollary 2).

4.3. Contract Implementation and Discussion

4.3.1. Default Risk. As shown in part iia of the proof of Proposition 6 in Online Appendix G, before the market price process converges, those farmers who are offered the contract and have a production cost less than $\bar{p}$ may periodically observe the realized market price higher than the contract price $p^o = \bar{p}$ at which they agreed to sell to the SE. They may realize that their average welfare is lower than that if they plant the crop and sell it directly to the market. Thus, these farmers may choose to default on the SE contract before the market stabilizes. However, we find that this possible default has *no* impact on the crop supply, and hence, the market price process is unchanged. This is because these low-cost farmers will plant the crop in every period regardless of whether they decide to sell the crop in the market or to the SE. Thus, contract price adjustment or incentives in any other form to prevent these farmers from defaulting may not be necessary.

4.3.2. Rate of Convergence. Similar to the result with strategic farmers, under the optimal buyout contract, a larger amount of type-S farmers does not change the market converging price but increases the market convergence rate and, thus, not only directly benefits most contract farmers themselves but also may indirectly increase the total welfare of both contract and noncontract farmers within a short period of time. Therefore, even though approaching and convincing farmers to participate in the contract farming can be time consuming, the SE should make the buyout contract accessible to as many farmers as possible if the budget permits.

However, different from the role of strategic farmers, the SE's contract is only effective in one period of every market cycle as it is executed by (naïve) farmers only when the market price is low. This leads to a *slower* market price convergence rate than that under the forward-looking behavior of strategic farmers in Section 3. This finding indicates that cultivating strategic farmers can be a more effective strategy over the long run than simply offering naïve farmers a buyout contract.

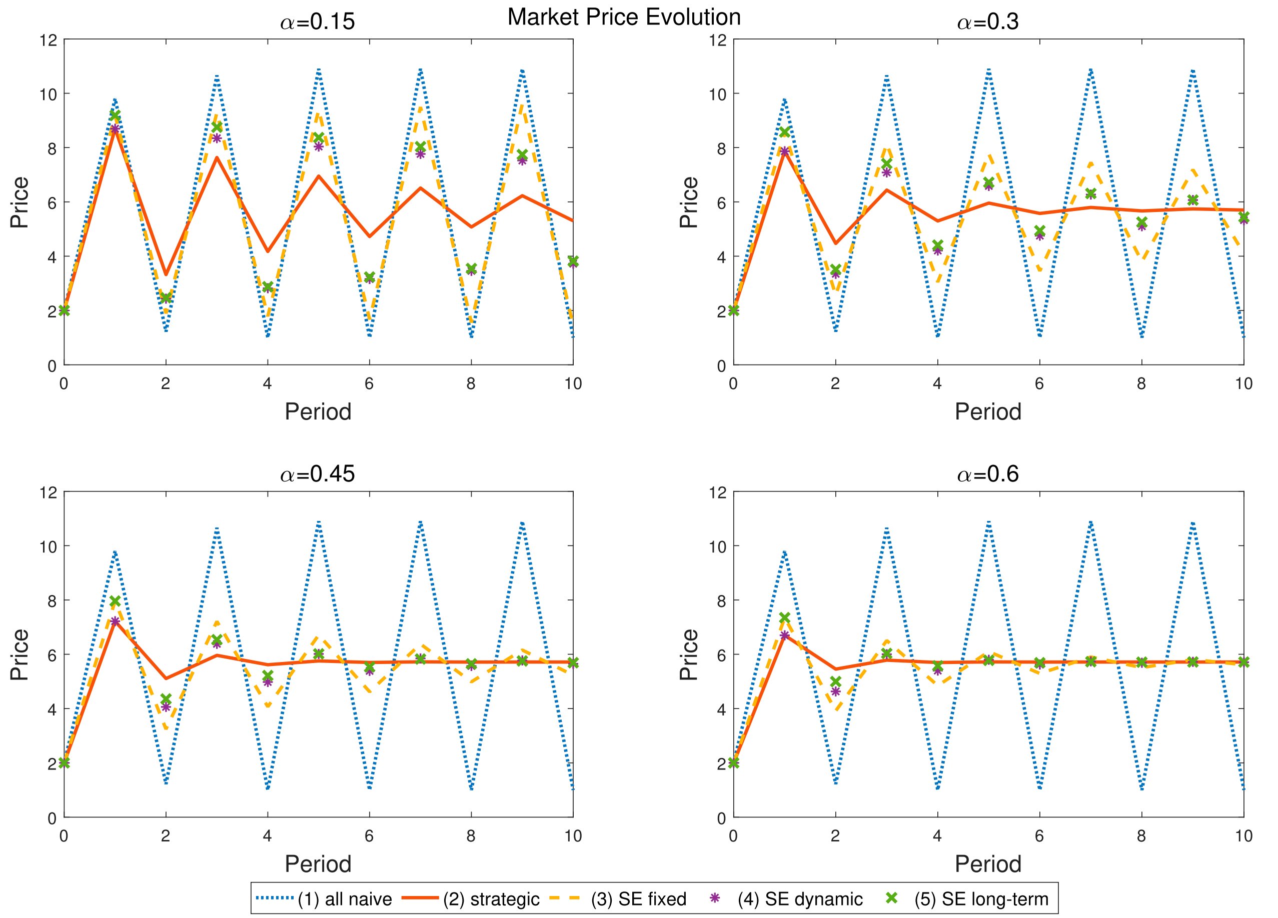
In Online Appendix D, we have also introduced two other types of contracts that hold the potential in expediting the price convergence. The first type is a time-varying contract that allows the SE to set a different buyout price p^o_t for a period t. It can be shown that in the long run the maximum of the total welfare is achieved when the price is stabilized at $\bar{p}$, and there is no time-varying price contract that can further improve the total welfare. Hence, for the time-varying price contract, we focus on the convergence rate instead of maximizing the welfare as in Problem (10). In Proposition D.1 we provide the time-varying contract that achieves the highest rate of the market price convergence. In addition, if the SE is able to endure losses, Proposition D.2 shows that the market-limiting price can be achieved in one period when α is sufficiently large. The second type is a long-term contract. If a type-S farmer accepts the contract, the farmer commits to cultivate the crop and sell it at p^o to the SE in *every* period. We find the optimal contract is also beneficial to both the SE and farmers. However, we also identify limitations and risks of implementing these forms of contract in the online appendix.

4.3.3. Numerical Comparison. We numerically compare the market price trajectories in all the models we have discussed so far, that is, the models with (1) all naïve farmers, (2) α fraction of strategic farmers, (3) the optimal fixed buyout contract, (4) the optimal time-varying contract, and (5) the optimal long-term contract. The latter three are offered by the SE to α fraction of type-S farmers. As shown in Figure 3, for the same given α, strategic farmers are the most efficient in stabilizing the market, and the SE's optimal time-varying and long-term contracts have similar performances that are better than that of the optimal fixed buyout contract.

5. Profit-Driven Enterprise

Although the important role of SEs and other social organizations in increasing farmers' welfare has been

Figure 3. (Color online) Numerical Comparison of Different Scenarios Across Various α



Note. Parameters: $b = 11, \bar{c} = 10, \Omega = 12$.

widely acknowledged, one cannot expect their participation in every market of the agriculture industry. In this section, we further study the commonly seen interactions between farmers and a profit-driven firm in agriculture supply chains who buys raw materials from farmers for resale or may use these materials to make products for sale. When all the farmers are naïve, we have seen that price uncertainty is a major obstacle to a stable stream of crop supply. Given that supply uncertainty leads to operational inefficiency, reducing the price risk and having a stable market supply may benefit all the stages along the supply chain. Therefore, it is often in the best interest of a profit-driven firm to plan ahead to contract with farmers to ensure a safe and steady supply of agricultural products. Given that companies may not want to wait for actions taken by others, it is important to examine how the market price risk and the resulting supply risk can be mitigated solely by a profit-driven firm. Specifically, we study the impact of a buyout contract offered by a for-profit firm instead of an SE.

Suppose the firm has a constant demand d in each period. If one unit of crop raw materials can be converted to one unit of final products, d can also be interpreted as the firm's target level of crop procurement. If the market supply $q_t \geq d$, the firm buys d units of raw materials from the market at the market price p_t. If $q_t < d$, the firm has to buy an additional quantity $d - q_t$ from an *external market* at a higher price p^m with $p^m > p_t$ for any $t \geq 0$. The external market is isolated from the focal market we have studied. The price difference $p^m - p_t$ can also be viewed as a penalty cost for those demands in excess of supply from the focal market. We start with all farmers in the population being naïve farmers. Just like the SE in the previous section, the firm offers a preseason procurement contract at the beginning of each period with a fixed price p^o to α fraction of naïve farmers. As before, we refer to farmers who are offered the contract as type-S farmers and the rest as type-N farmers.

Assumption 7. $\alpha < d < \frac{\Omega - \bar{p}}{b}$.

Note that $d < \frac{\Omega - \bar{p}}{b}$ ensures that a stable market can provide sufficient supply to meet the firm's demand, and $d > \alpha$ states that the production by type-S farmers alone is insufficient to satisfy all of the firm's demand. Assumption 7 ensures that the firm desires a stable market and has the incentive to induce both types of farmers to produce enough of the crop for the firm.

The total procurement cost to meet demand in period t is

$$f_t(p^o) := \begin{cases} p^o \min\{q_t^o, d\} + p_t[\min\{q_t, d\} - q_t^o]^+ \\ \quad + p^m(d - q_t)^+ & \text{if } p^o > p_{t-1}, \\ p_t \min\{q_t, d\} + p^m(d - q_t)^+ & \text{otherwise,} \end{cases} \tag{11}$$

where $[x]^+ := \max\{x, 0\}$; p_t is the market price that evolves according to Equation (8); $q_t^o = \alpha F(p^o)$ is the amount of crop produced by the type-S (contract) farmers; and q_t is the total supply from the focal market, which, as an inverse function of the market price, is equal to $\frac{\Omega - p_t}{b}$ by definition. Within period t, the firm fulfills its demand by using different sources in the following pecking order. When $p^o > p_{t-1}$ and, thus, some type-S farmers accept the contract, the firm first purchases at most $\alpha F(p^o)$ from contract farmers at unit price p^o and then sources from the market at unit cost p_t and finally resorts to the external market with unit cost p^m until the demand is fully satisfied. When $p^o \le p_{t-1}$, the firm first buys from the market and then from the external market if necessary.

To increase the total quantity of potentially less costly supply $q_t^o = \alpha F(p^o)$ from the farmers, the firm could either increase α by making the contract accessible to more farmers or raise the buyout price p^o, both of which come at a cost. (In Section 6.2, we consider yield uncertainty. When yield uncertainty is pronounced, the firm may want to further increase α and p^o to secure supply.)

Different from the SE's objective, the firm's goal is to minimize its average long-term cycle procurement cost, that is,

$$\min_{p^o} \lim_{T\to\infty} \frac{1}{T} \sum_{i=1}^{T} [f_{2i-1}(p^o) + f_{2i}(p^o)]. \tag{12}$$

Farmers' planting decisions and, hence, the market evolution and farmers' welfare under the buyout contract with a constant price are the same as specified in Propositions 5 and 6(ii) when the contract is offered by the SE.

Proposition 7 (Socially Beneficial Rationality of For-Profit Firm). *Suppose Assumptions 1–7 hold. Denote by p_{2i-1}^n the higher price in any given cycle i when all farmers are naïve farmers. Suppose $\lim_{i\to\infty} \frac{\Omega - p_{2i-1}^n}{b} < d$. If the buyout price is set to $p^o = \bar{p}$ for all periods, then*

(i) *The market price converges to $\bar{p}$.*

(ii) *There exists an $i' > 0$ such that the firm obtains a higher profit with the contract than without in any cycle $i > i'$. In particular, if $b = \bar{c}$, $p^o = \bar{p}$ is an optimal solution to the firm's problem (Problem 12).*

(iii) *In both the short and long run, farmers' welfare improvement is the same as specified in Proposition 6(ii).*

Proposition 7 provides sufficient conditions under which the buyout contract with $p^o = \bar{p}$ benefits the profit-driven firm and farmers in both the short and long terms. The market will be stabilized, eliminating the negative impact of farmers' shortsighted behavior and providing a stable and low-cost crop supply to the firm. Specifically, $\lim_{i\to\infty} \frac{\Omega - p_{2i-1}^n}{b} < d < \frac{\Omega - \bar{p}}{b}$ ensures that a stable market can provide sufficient supply to meet the firm's demand, whereas an unstable market may not. As mentioned, the condition $d > \alpha$ in Assumption 7 further ensures that the production by type-S farmers alone (at most α) is insufficient to satisfy all of the firm's demand. Hence, these conditions ensure that the firm has an incentive to stabilize the market and induce both types of farmers to produce enough of the crop for the firm.

Moreover, when $b = \bar{c}$, Proposition 7(ii) shows that the buyout contract with $p^o = \bar{p}$ is indeed optimal among all buyout contracts under the long-run average procurement cost criterion. However, when $b > \bar{c}$, that is, when the market price is relatively more sensitive to the market supply, the firm may be driven by the nature of profit-seeking to choose a different contract from $p^o = \bar{p}$.

Remark 1 (Speculative Firm). In this remark, we illustrate the firm's speculative behavior and discuss why the for-profit firm may not want to completely eliminate the price fluctuation. Suppose Assumptions 1–7 hold and $b > \bar{c}$. For any given market price $p_{2i'} < \bar{p}$, the firm is able to control the market prices to alternate between two fixed prices, that is, $p_{2i'}$ and a higher price $\bar{p} + \frac{b(1-\alpha_2)}{\bar{c}}(\bar{p} - p_{2i'})$. The firm achieves this outcome by setting the contract price to $p^o = p_{2i'} + \frac{\alpha_2}{\alpha}(\bar{p} - p_{2i'})$ for all $t \ge 2i'$. The price fluctuation enables the firm to buy from contract farmers at p^o in odd periods when the market price is expected to be high and buy directly from the market in even periods when the market price is expected to be low.

The for-profit firm gets long-term benefits from this speculative behavior only if there is a sufficient amount of supply and the firm does not have to buy from the expensive external market. This condition is achieved as long as the lower market price $p_{2i'}$ is not too low; that is, $p_{2i'} \ge \bar{p} - \frac{1}{1-\alpha_2}(\bar{p} - \bar{c}d)$. The firm's profit in the long run is greater than that when the contract price is $p^o = \bar{p}$, and the increased profit comes at the expense of a decrease of welfare for farmers with relatively high production costs (i.e., $c \ge \underline{c}$).

6. Extensions

The unstable market supply resulting from price fluctuations is often exacerbated by a host of endogenous and exogenous causes. For example, farmers may choose which crop to plant among multiple options based on their market prices, and this decision can be influenced by crop production yield, which is affected by weather, insect pests, etc. In this section, we first extend Section 3 to a two-crop setting in which both naïve and strategic farmers choose to cultivate one of two types of crops. In other words, the outside option of planting one crop for a farmer is *endogenized* as the value of planting the other. We then further extend this model to capture the production yield uncertainty. The same extensions can be naturally made to the settings in Sections 4 and 5.

6.1. Two Crops

We consider farmers who choose to plant one of two types of crops in each period. We use A and B to denote the two crops. In line with the settings in the previous sections, we assume a farmer's production costs of planting crops A and B are c and $\bar{c}-c$, respectively, where c is uniformly distributed on $[0,\bar{c}]$. In addition to capturing the heterogeneity of farmers' production costs, the assumed cost structure reflects two plausible reasons: first, each farmer may have different production costs for different crops; second, no farmer has cost advantages over other farmers with both crops. The analysis can be extended to settings with production costs in more general forms.

We first derive the quantities of crops A and B produced by naïve and strategic farmers. Under the assumed production cost structure, a naïve farmer's perceived utility of cultivating crops A and B is $u_t^{A,n} = p_{t-1}^A - c$ and $u_t^{B,n} = p_{t-1}^B - (\bar{c}-c)$, respectively. Similarly, the expected utility of planting crop A for a strategic farmer who rationally anticipates the market price is $u_t^{A,s} = p_t^A - c$, and the expected utility of planting crop B is $u_t^{B,s} = p_t^B - (\bar{c}-c)$. Compared with the single crop model in Section 3, the value of planting one crop here can be taken as the endogenous outside option of planting the other.[1] We assume $u_t^{A,\tau}$ and $u_t^{B,\tau}$ for $\tau \in \{n,s\}$ are all nonnegative to avoid the degeneration to the single-crop model. A naïve or strategic farmer will cultivate crop A if $u_t^{A,\tau} \geq u_t^{B,\tau}$ for $\tau \in \{n,s\}$ and otherwise will cultivate crop B. Thus, in period t, the quantities of crops A and B produced by naïve farmers are

$$q_t^{A,n} = (1-\alpha)\mathsf{P}(u_t^{A,n} \geq u_t^{B,n}) \quad \text{and}$$
$$q_t^{B,n} = (1-\alpha)\mathsf{P}(u_t^{A,n} < u_t^{B,n}). \tag{13}$$

Similarly, the quantities of crops A and B produced by strategic farmers are $q_t^{A,s} = \alpha\mathsf{P}(u_t^{A,s} \geq u_t^{B,s})$ and $q_t^{B,s} = \alpha\mathsf{P}(u_t^{A,s} < u_t^{B,s})$. For ease of exposition, we assume crops A and B have the same market size Ω. Then the market-clearing prices of crops A and B are $p_t^A = \Omega - b(q_t^{A,n} + q_t^{A,s})$ and $p_t^B = \Omega - b(q_t^{B,n} + q_t^{B,s})$.

Proposition 8. *Suppose Assumptions 1–3 hold.*

(i) *If $g(\alpha) \geq 1$, the market price process in each market does not converge.*

(ii) *If $g(\alpha) < 1$, the market prices of crops A and B are $p_t^A = \Omega - \frac{b}{2} - \Delta_t(\alpha)$ and $p_t^B = \Omega - \frac{b}{2} + \Delta_t(\alpha)$, where $\Delta_t(\alpha) = \frac{1}{2}(-g(\alpha))^{t-1}(p_1^A - p_1^B)$, and both converge to $\Omega - \frac{b}{2}$ as $t \to \infty$.*

Proposition 8 shows that when farmers are able to choose one of two crops to plant in each period, the market evolution is similar to the patterns in the single-crop model (see Proposition 1). When there is a lack of sufficient number of strategic farmers, the market price process for each crop does not converge and eventually alternates between two prices; when there is a sufficiently large number of strategic farmers, the price process of each crop will converge to $\Omega - \frac{b}{2}$, which is independent of the segment size of strategic farmers, α. Comparing with the single-crop model, the key difference is that now the farmers' outside option of cultivating one crop is endogenized as the value of cultivating the other crop. In particular, the high price of one crop at the end of a period encourages naïve farmers to plant this crop in the next period, exacerbating the shortage of the other crop. Hence, the market prices for two crops tend to wax and wane in alternation.

The limiting price $\Omega - \frac{b}{2}$ in Proposition 8(ii) implies that when there are sufficient strategic farmers, eventually half of the farmers with the cost advantage for crop A, that is, $c < \frac{\bar{c}}{2}$, always cultivate crop A, and the other farmers always cultivate crop B in each period. Farmers are divided exactly in half because the potential market sizes of both crops are assumed to be the same as Ω. It can be shown that, when the two crops have different market sizes, the market price of each crop will still converge as long as (1) there are enough strategic farmers and (2) the difference between the market sizes of the two crops is not too large. Over the long run, the crop with a larger market size attracts more than half of the farmers. In terms of the farmers' welfare, the same statement as in Proposition 3 still holds in the two-crop model because strategic farmers continue to help stabilize the market prices for both crops. That is, our finding about strategic farmers' socially beneficial rationality continues to hold for the two-crop model.

6.2. Random Yield

Now we extend the two-crop model by considering yield uncertainty in the farmers' harvest. This uncertainty, which is attributed to uncontrollable external factors (e.g., weather, water supply, pests), captures the fact that the harvest quantity is often different from the quantity actually planted. We refer to the former as the *random yield* and the latter as the *production quantity*. We capture yield uncertainty by the ratio of the random yield to the production quantity and assume that the yield uncertainty in period t for all crops in the same district is the same, denoted by γ_t.

In line with the two-crop model, we denote by $\hat{q}_t^{A,\tau}$ and $\hat{q}_t^{B,\tau}$ for $\tau \in \{n, s\}$ the farmers' production quantity of crops A and B given the most recent market prices p_{t-1}^A and p_{t-1}^B, respectively. The random yields of the two crops are $Q_t^{A,\tau} = \hat{q}_t^{A,\tau}\gamma_t$ and $Q_t^{B,\tau} = \hat{q}_t^{B,\tau}\gamma_t$ for $\tau \in \{n, s\}$.

We assume that yields γ_t for all $t \geq 1$ are independent and identically distributed random variables with finite variance and that they are independent of farmers' production costs. In a typical production environment, $\gamma_t \leq 1$, however, this is not a requirement of our model. We use $\gamma_t = 1$ to represent an average or normal external condition. The case of $\gamma_t > 1$ can capture a growing season when crops grow very well, and $\gamma_t < 1$ captures a season with extreme weather or blight that dooms a harvest. We assume $\mathsf{E}(\gamma_t) = 1$.

Now we derive the farmers' production quantities and the corresponding market prices in a period. For naïve farmers, the production quantities $(\hat{q}_t^{A,n}, \hat{q}_t^{B,n})$ can be written in the same way as $(q_t^{A,n}, q_t^{B,n})$ in Equation (13) under the assumption that $\mathsf{E}(\gamma_t) = 1$. In contrast, the production quantities of strategic farmers depend on the rationally anticipated market prices, which are affected by the yield. Specifically, the perceived expected utilities of planting crops A and B can be written as $u_t^{A,s} = E[\gamma P_t^A] - c$ and $u_t^{B,s} = E[\gamma P_t^B] - (\bar{c} - c)$, where γ is a representative random variable whose distribution is the same as γ_t for $t \geq 1$ and is independent of these γ_t, and P_t^A and P_t^B are the random market prices for period t (see below). Then the corresponding production quantities of crops A and B can be expressed as $\hat{q}_t^{A,s} = \alpha \mathsf{P}(u_t^{A,s} \geq u_t^{B,s})$ and $\hat{q}_t^{B,s} = \alpha \mathsf{P}(u_t^{A,s} < u_t^{B,s})$. The resulting market-clearing prices are now random, depending on the random yields of the two crops, that is, $P_t^A = \Omega - b(Q_t^{A,s} + Q_t^{A,n})$ and $P_t^B = \Omega - b(Q_t^{B,s} + Q_t^{B,n})$.

Next we show the convergence of the random market price processes in a probabilistic sense.

Proposition 9. *Suppose Assumptions 1–3 hold,* $\text{var}[\ln \frac{(1-\alpha)b\gamma}{\bar{c}+\alpha b \mathsf{E}[\gamma^2]}] < \infty$, *and* $b(1-2\alpha)\mathsf{E}[\gamma^2] \leq \bar{c}$. *Define* $I(\alpha, \gamma) := \ln \frac{(1-\alpha)b}{\bar{c}+\alpha b \mathsf{E}[\gamma^2]} + \mathsf{E}[\ln \gamma]$.

(i) *If* $I(\alpha,\gamma) \leq 0$, *then the random market price processes* P_t^A *and* P_t^B *converge in probability toward the same random variable* $\bar{P} := \Omega - \frac{b}{2}\gamma$; *that is,*

$$\lim_{t\to\infty} \mathsf{P}(|P_t^A - \bar{P}| > \epsilon) = \lim_{t\to\infty} \mathsf{P}(|P_t^B - \bar{P}| > \epsilon) = 0 \text{ for any } \epsilon > 0.$$

Moreover, the price difference between two crops converges to zero in probability as t goes to ∞.

(ii) *If* $I(\alpha,\gamma) > 0$, *then the random market price processes do not converge.*

As $(1-2\alpha)\mathsf{E}[\gamma^2]$ and $I(\alpha,\gamma)$ decrease in $\alpha > 0$, Proposition 9 shows that, compared with a market in which all farmers are naïve, the market price processes are more likely to converge when there are more strategic farmers. When the condition $I(\alpha,\gamma) \leq 0$ holds, the price processes converge to a random variable $\bar{P}$, which is an affine transformation of the yield uncertainty γ. If $\gamma = 1$, we recover the deterministic two-crop model; see Proposition 8(ii). When the market prices converge to the random variable $\bar{P} := \Omega - \frac{b}{2}\gamma$, the price difference between two crops diminishes, and hence, the fluctuation of market prices remaining in the market is completely attributed to the yield uncertainty.

7. Conclusion

In developing countries, the price fluctuation in agricultural markets is blocking the path to prosperity for small-scale farmers. Although the burgeoning literature on sustainable operations studies the value of disclosing market information for price discovery and how that affects farmers' welfare, little attention has been paid to farmers' heterogeneous capability in obtaining and processing market information. In reality, only farmers who are educated and not in remote areas may obtain and utilize the market information in their decision making. It, thus, gives rise to the concern whether efforts to disseminate market information treat all farmers fairly and whether the market is evolving in a socially desirable way.

In this paper, we offer a stylized multiperiod model to study farmers' dynamic crop-planting decisions and their impact on the market prices. We consider both naïve farmers who react shortsightedly to the latest market price and strategic farmers who are able to collect and utilize market information to anticipate rationally the near-future market price. Our model builds a microfoundation to capture the root cause of the price fluctuations observed in many agricultural markets. That is, because naïve farmers base their crop-planting decisions on the latest market price, they cyclically herd in planting the crop, thus leading to recurring overproduction and price slashing. We find that the forward-looking behavior of strategic farmers could alleviate the herding behavior, therefore being both individually rational and socially beneficial in that it can stabilize the market price process and increase farmers' total welfare. However, to sustain this notion of socially beneficial rationality, there must be a sufficient number of strategic farmers to collectively move the needle.

Another major finding of this paper is that even when it fails to cultivate strategic farmers, both social entrepreneurs and for-profit firms can benefit farmers as well as themselves by offering a preseason buyout contract to a fraction of farmers. Those farmers then only need to base their crop-planting decisions on the price offered by the firm. However, although a carefully designed contract can improve the total social welfare and lead to smaller individual welfare gaps among farmers, a nonsocially optimal contract may reflect a social entrepreneur's over-subsidy tendency or a for-profit firm's speculative incentive to mitigate but not eliminate the market price fluctuation, preventing farmers from achieving the most welfare. Finally, we also extend our model with strategic farmers to account for multiple crops and yield uncertainty, and our analysis confirms the role of strategic farmers in improving farmers' welfare.

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Appendix. Summary of Results

We summarize our main results in the following tables.

Table A.1. Price Evolution and Convergence

Naive farmers $1-\alpha$ and a fraction α of	Condition	Market price evolution	Converges to $\check{p}$ =	Convergence rate $\frac{\lvert p_{2i+1}-\check{p}\rvert}{\lvert p_{2i-1}-\check{p}\rvert}$
(1) Naïve farmers	$b<\bar{c}$	$p_t=\bar{p}+\left(-\frac{b}{\bar{c}}\right)^t(p_0-\bar{p})$	$\bar{p}$	$\left(\frac{b}{\bar{c}}\right)^2$
	$b\geq\bar{c}$		No convergence	
(2) Strategic farmers	$g(\alpha)<1$	$p_t=\bar{p}+[-g(\alpha)]^t(p_0-\bar{p})$	$\bar{p}$	$g^2(\alpha)$
	$g(\alpha)\geq 1$		No convergence	
(3) Type-S farmers under contract with price $\bar{p}$	$\alpha>\alpha_2$	$p_1=\Omega-\alpha\frac{b}{\bar{c}}\bar{p}-(1-\alpha)\frac{b}{\bar{c}}p_0$, $p_{2i-1}=\bar{p}+\left[\frac{(1-\alpha)b^2}{\bar{c}^2}\right]^{i-1}(p_1-\bar{p})$, $p_{2i}=\Omega-\frac{b}{\bar{c}}p_{2i-1}$	$\bar{p}$	$(1-\alpha)\frac{b^2}{\bar{c}^2}$
	$\alpha\leq\alpha_2$		No convergence	
(4) Type-S farmers under time-varying contract	$\alpha>\alpha_1$	$p_{2i-1}=\frac{\bar{c}}{\bar{c}+\alpha b}\left[\Omega-\frac{(1-\alpha)b}{\bar{c}}p_{2i-2}\right]$, $p_{2i}=\Omega-\frac{b}{\bar{c}}p_{2i-1}$	$\bar{p}$	$>(1-\alpha)\frac{b^2}{\bar{c}^2}$
	$\alpha\leq\alpha_1$		NA	
(5) Type-S farmers under long-term contract with price $\bar{p}$	$\alpha>\alpha_1$	$p_t=\bar{p}+\left[-\frac{(1-\alpha)b}{\bar{c}}\right]^t(p_0-\bar{p})$	$\bar{p}$	$\left[(1-\alpha)\frac{b}{\bar{c}}\right]^2$
	$\alpha\leq\alpha_1$		No convergence	
(6) Backward-looking farmers (see Online Appendix B)	$b<\bar{c}$	$p_t=\Omega-\frac{b}{\bar{c}}\left(1-\frac{\alpha}{2}\right)p_{t-1}-\frac{b}{\bar{c}}\frac{\alpha}{2}p_{t-2}$	$\bar{p}$	NA
	$b\geq\bar{c}$		NA	NA

Notes. $g(\alpha):=\frac{(1-\alpha)b}{\bar{c}+\alpha b}$, $\alpha_1:=1-\frac{\bar{c}}{b}$, and $\alpha_2:=1-\frac{\bar{c}^2}{b^2}$. We omit the trivial scenarios when market prices take extremely high or low values (i.e., when all farmers or no farmers plant the crop). NA, not applicable.

Table A.2. Farmer Welfare Summary

Scenario	Short-run welfare	Long-run welfare ($i\to\infty$)	Comparison ($c\geq\underline{c}$)
(1)	$w_i^n(c)=\begin{cases}\frac{p_{2i-1}+p_{2i}}{2}-c & \text{if } c\leq p_{2i-2}\\ \frac{p_{2i}-c}{2} & \text{if } p_{2i-2}<c\leq p_{2i-1}\\ 0 & \text{if } c>p_{2i-1}\end{cases}$	$=w_i^n(c)$	
(2)	$w_i^s(c)=\begin{cases}\frac{p_{2i-1}+p_{2i}}{2}-c & \text{if } c\leq p_{2i-2}\\ \frac{p_{2i}-c}{2} & \text{if } p_{2i-2}<c\leq p_{2i-1}\\ 0 & \text{if } c>p_{2i-1}\end{cases}$	$=\begin{cases}\bar{p}-c & \text{if } c\leq\bar{p}\\ 0 & \text{if } c>\bar{p}\end{cases}$	$>$(1); $>\bar{w}_i^s$ in (3); $>w_i^n$ in (2)

Table A.2. (Continued)

Scenario	Short-run welfare	Long-run welfare ($i \to \infty$)	Comparison ($c \geq \underline{c}$)
	$w_i^n(c) = \begin{cases} \frac{p_{2i-1}+p_{2i}}{2} - c & \text{if } c \leq p_{2i} \\ \frac{p_{2i-1}-c}{2} & \text{if } p_{2i} < c \leq p_{2i-1} \\ 0 & \text{if } c > p_{2i-1} \end{cases}$	$= \begin{cases} \bar{p} - c & \text{if } c \leq \bar{p} \\ 0 & \text{if } c > \bar{p} \end{cases}$	$>(1)$; $>\bar{w}_i^n$ in (3); $>\bar{w}_i^n$ in (5) if $c > p_{2i-2}$
(3)	$\bar{w}_i^s(c) = \begin{cases} \frac{\bar{p}+p_{2i}}{2} - c & \text{if } c \leq p_{2i-2} \\ \frac{p_{2i}-c}{2} & \text{if } p_{2i-2} < c \leq p_{2i-1} \\ 0 & \text{if } c > p_{2i-1} \end{cases}$	$= \begin{cases} \bar{p} - c & \text{if } c \leq \bar{p} \\ 0 & \text{if } c > \bar{p} \end{cases}$	$>(1)$
	$\bar{w}_i^n(c) = \begin{cases} \frac{p_{2i-1}+p_{2i}}{2} - c & \text{if } c \leq p_{2i-2} \\ \frac{p_{2i}-c}{2} & \text{if } p_{2i-2} < c \leq p_{2i-1} \\ 0 & \text{if } c > p_{2i-1} \end{cases}$	$= \begin{cases} \bar{p} - c & \text{if } c \leq \bar{p} \\ 0 & \text{if } c > \bar{p} \end{cases}$	$>(1)$; $>\bar{w}_i^s$ in (3)
(4)	$\bar{w}_i^s(c)$ NA.	$= \begin{cases} \bar{p} - c & \text{if } c \leq \bar{p} \\ 0 & \text{if } c > \bar{p} \end{cases}$	$>(1)$
	$\bar{w}_i^n(c)$ NA.	$= \begin{cases} \bar{p} - c & \text{if } c \leq \bar{p} \\ 0 & \text{if } c > \bar{p} \end{cases}$	$>(1)$
(5)	$\bar{w}_i^s(c) = \begin{cases} \bar{p} - c & \text{if } c \leq \bar{p} \\ 0 & \text{if } c > \bar{p} \end{cases}$	$= \begin{cases} \bar{p} - c & \text{if } c \leq \bar{p} \\ 0 & \text{if } c > \bar{p} \end{cases}$	$>(1)$; $>\bar{w}_i^s$ in (3); $>\bar{w}_i^n$ in (5) if $c > p_{2i-2}$
	$\bar{w}_i^n(c) = \begin{cases} \frac{p_{2i-1}+p_{2i}}{2} - c & \text{if } c \leq p_{2i-2} \\ \frac{p_{2i}-c}{2} & \text{if } p_{2i-2} < c \leq p_{2i-1} \\ 0 & \text{if } c > p_{2i-1} \end{cases}$	$= \begin{cases} \bar{p} - c & \text{if } c \leq \bar{p} \\ 0 & \text{if } c > \bar{p} \end{cases}$	$>(1)$; $>\bar{w}_i^n$ in (3)

Notes. In scenarios (2)–(5), we assume $b \geq \bar{c}$. For all five scenarios, we assume the market convergence conditions (in Table A.1) hold.

Endnote

[1] There are papers that study the farmers' planting decisions when there are crop rotation benefits, such as a larger yield and lower farming costs on rotated farmland (see, e.g., Boyabatli et al. 2019 and related papers mentioned therein). Our study focuses more on farmers' planting decisions as reactions to the market-price dynamics.

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