Agricultural Cooperative Pricing of Premium Product

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We consider the problem of pricing-setting by a cooperative for purchase of an agricultural product with the following characteristics: (1) the open-market price for the product depends on yield and quality, and (2) the quality of the product is influenced by farmer investments over the growing season. The cooperative purchases product from its member farmers according to a quality-dependent price schedule. To be viable over the long-term, the price schedule must be competitive with the open market from both the perspective of the farmer and the cooperative—the farmer should not be underpaid and the cooperative should not overpay relative to the open market. One alternative for achieving this condition is to set prices that largely mimic the open market, and indeed, we find this approach in use at a major cooperative that we studied.

We identify and analyze an alternative pricing scheme that is simple to implement. While the pricing scheme leads to higher volatility in farmer profits, it shows potential to significantly improve profits. For a risk-neutral farmer, the pricing scheme incentivizes the farmer to make decisions consistent with maximizing expected system profit. We find that the increase in profit compared to status quo is largely dictated by the magnitude of the cooperative's brand equity—the degree to which the cooperative can command a higher price for the product than a farmer. If a farmer is sufficiently risk averse, then the pricing scheme should be augmented by crop insurance. Data from this industry suggest that cooperative and farmer profits can increase by 10-20% over the current open-market pricing approach.

1. Introduction

This paper develops a pricing scheme for an agricultural cooperative firm that has the goal of incentivizing its farmer members to invest in quality improvement efforts. Our motivation comes from Tariş, the second largest extra virgin olive oil (EVOO) producer in Turkey. According to the 2014 Nielsen report, Tariş commands 25.9% of the EVOO retail market share in the country, and has distribution and sales in more than 30 countries. Tariş has long been a union of farmers dating back to 1915 during the Ottoman Empire, and has served a similar purpose since the formation of the Republic of Turkey in 1923. Since 1935, during the government-controlled period, the company has implemented what it calls a "Price Support System" (PSS) where olives are purchased at a pre-determined price. PSS has allowed for government interventions such as subsidies, and has protected the farmer by providing a guaranteed payment. The farmer has continued to operate under yield uncertainty where the crop yield is influenced by fluctuations in weather conditions and diseases.

The economic landscape changed in 2000. Following the economic crises in late 1990s, the loan agreement from the International Monetary Fund forced the government of Turkey to relinquish its control over Tariş. This agreement resulted in an autonomous company as a union of farmers acting as an independent enterprise since June 2000. As a result, Tariş today is motivated to assure long-term profitability. The new management team has decided to put effort into marketing, branding, and packaging, while continuing to encourage its farmers to invest in quality improvements that would provide the firm financial stability in the absence of the government support. In February 2001, the new firm has established a revised pricing scheme that pay farmers according to EVOO prices in the open market (e.g. the international EVOO market). We refer to the present pricing scheme as the *open-market pricing policy* (OMPP) and describe it below as the benchmark pricing policy in our analysis.

The farmer receives two payments under OMPP. The quality-dependent payment schedule is posted a few months prior to the harvest time and is paid to the farmer after the harvest (end of November or early December) and pressing of olives for oil (the day after harvest). This first payment is based on the quality level determined by a test that reveals the oleic acidity of the oil; specifically, a lower level of oleic acidity receives a higher price. Three months after the production of EVOO, the cooperative makes a second payment to its farmers. This second payment is equal to the difference between the (realized) international open-market prices for the grade of olive oil (based on oleic acidity) and the first payment made at the time of harvest. Thus, the present payment scheme leads to a total payment to the farmer that mimics the open-market prices in international markets. Both payments are dependent on the quality designated by oleic acidity per liter of olive oil. It is important to note here that the farmer operates under two forms of uncertainty in this pricing scheme: the farmer faces yield uncertainty and randomness in the economic factors that influence the open-market EVOO prices. The open market-EVOO prices are obtained through Mercado de Futuros del Aceito de Oliva (MFAO), often referred to as the Olive Oil Futures Market. Figure 1 demonstrates the fluctuations in EVOO prices in the last 30-year time interval.

Figure 1. Historical EVOO prices in the world market. Source: The Olive Oil Futures Market known as the Mercado de Futuros del Aceito de Oliva (MFAO) from February 1986 to February 2016.

Prior to, and during, the growing season, farmers make investments that affect the quality of the crop (e.g., cleaning branches and tending to the trees after harvest, tilling the land, investing in fertilizers, investing in harvesting methods). While OMPP transfers the farmer's risk exposure to open-market price uncertainty to the cooperative, the final purchase price is not determined until a few months after the oil is produced. Moreover, the farmer continues to operate under yield uncertainty. One of the consequences of OMPP according to the executives of Tariş is that its member farmers under-invest in quality. Our analysis confirms this observation and explains the reasons behind this phenomenon. We find that farmer under-investment in quality stems from two underlying causes. First, the cooperative is able to command a higher price for olive oil than a farmer. It is a much larger entity with well-established sales channels, high name recognition among consumers (i.e., manifested in brand equity), and operates temperature-controlled storage facilities that are essential to maintaining quality of premium olive oil over time. Farmers, on the other hand, do not have the ability to make the investment in temperature-controlled storage, and therefore, they cannot sell directly in the open market over time. Second, farmers are risk averse, and the cooperative is risk neutral. Our work shows that the degree of under-investment increases with the cooperative's pricing power and with the farmer's risk aversion.

We develop a model that considers a large cooperative's pricing scheme for a premium product (e.g., such as EVOO). The cooperative has risk-averse farmers who consider a value-at-risk constraint when determining the level of investment in crop quality. The farmer operates under yield uncertainty and open-market price uncertainty, and the cooperative determines how to pay the farmers for their crop.

Our paper develops a new payment scheme and offers new prescriptions to cooperatives that sell premium products in their efforts to incentivize its member farmers in making investments in quality. Our proposed pricing scheme follows the structure of a two-part tariff that is a widely used volume-dependent price scheme in practice. Under a classical two-part tariff, the price paid per unit decreases with the volume purchased. More specifically, one "part" of purchase price is proportional to volume and the other part is independent of volume; the per unit contribution of the second part decreases with volume, resulting in a quantity-discount pricing schedule. It is well known that, compared to a single-part price-volume schedule (i.e., price proportional to volume), a two-part tariff can be structured to increase system profit and to allocate system profit among buyer and seller as desired. In effect, a single-part price-volume schedule incentivizes the buyer to under-order relative to system optimal, a phenomenon originally identified by Spengler (1950) and known as double marginalization. By comparison, if the constant of proportionality in a two-part tariff is equal to system marginal cost, then the reward structure of the buyer is aligned with the reward structure of the system, leading to system-optimal purchase quantities. The second part of the two-part tariff is what allows system profit to be allocated among buyer and seller in an equitable manner.

We find that the key insight of Spengler (1950) and the consequent power of a two-part tariff in a *price-volume* schedule translates in a natural way to a *price-quality* schedule, and can result in meaningful increases in profit to both farmer and cooperative. In particular, our proposed pricing scheme sets a price per unit comprised of two parts—one part that is proportional to the value of quality of finished product and a second part that is independent of quality and yield. If the first part is aligned with the value of quality to the system, then the farmer reward structure is aligned with the system reward structure, leading to system optimal investment in quality. We refer to our proposed pricing scheme as the *brand markup pricing policy* (BMPP).

An important aspect of our setting is farmer risk-aversion, which introduces a dimension that, to our knowledge, has not appeared in the literature on two-part tariffs. In particular, we note that a price-volume contract that conforms to a two-part tariff can improve system profit through an increase in purchase volume, which in the presence of uncertainty, can increase risk. In the context of our setting, we find that BMPP introduces greater risk to the farmer. We characterize the negative effect of farmer risk aversion on system performance, both for OMPP and BMPP. To offset this effect, we propose that BMPP be augmented by crop insurance offered through the cooperative to its member farmers. We show that this combination—BMPP and crop insurance—encourages farmers to invest in a level of quality that maximizes system profit and allows all parties to be better off. Crop insurance is currently being piloted by the cooperative.

The remainder of this paper is organized as follows. Section 2 presents the related literature. Section 3 introduces the model, and Section 4 provides its analysis. Section 5 demonstrates the financial impact from using our pricing policy through data provided by Tariş. Section 6 concludes and provides a summary of managerial insights. All proofs and technical derivations are relegated to the appendix.

2. Related Literature

Our study is relevant to various research streams including contract farming, supply chain contracting and coordination, and supply and quality uncertainty. Our work brings novelties to the existing publications in these areas by involving farmer risk-aversion and quality-based pricing contracts.

Coordination mechanisms have been widely studied in supply chains, and there have been extensive set of publications that examine revenue-sharing and buyback contracts (see Cachon and Lariviere 2005, Tsay et al. 1999, Wang et al. 2004, Webster and Weng 2000). These studies advocate the design of contracts from a coordination perspective (see Ho and Zhang 2008, Moorthy 1987, Ye et al. 2015), including the studies that develop a two-part tariff as a remedy to the double marginalization phenomenon identified by Spengler (1950). Two-part tariffs in pricing contracts are also used in franchising settings (see Gal-Or 1995 and Lafontaine and Kaufmann 1994).

Contract farming refers to the production of agricultural produce with advance agreements formalized with contracts. Singh (2005) describes that these contracts ensure that suppliers would provide an agricultural commodity of a type, at a specific time and at a previously-agreed price, and in the quantity required to a known buyer. Bijman (2008) presents an overview of the contract farming practices in developing countries. Relying on qualitative surveys, his study asserts that contract farming strengthens vertical coordination in agricultural supply chains from a quality management perspective. de Zegher et al. (2016) examine the effects of commodity-based sourcing of agricultural products versus direct sourcing on farmers' incentives to invest in quality. Ye et al. (2015) is the most relevant paper to our study. They consider pricing and production decisions in a decentralized agricultural supply chain where the farmer follows a conditional-value-at-risk measure. Our paper extends their study in two ways. First, we incorporate quality investment decisions as a second lever on the part of the farmer's compliance with the contractual terms. Second, we examine the influence of random open-market prices on the contracts between farmers and processors. Zhao and Wu (2011) and Cai et al. (2010) investigate whether revenue-sharing contracts can coordinate agricultural supply chains through revenue-sharing contracts. We extend both studies by incorporating the quality investment decision of the farmer and by considering farmers' risk aversion.

Few publications examine quality concerns within revenue sharing and two-part tariff structures. Gurnani and Erkoç (2008) examine the impact of quality improvement in designing supply chain coordinating contracts through a two-part tariff structure. In their paper, the manufacturer has the power to determine the contracts, and specifically, the wholesale price. Moreover, it is the retailer that puts effort in promotion in order to increase demand and sales. In our case, the retailer is providing a pricing mechanism to incentivize the supplier to improve quality. Moreover, we examine the impact of supplier risk aversion. Focusing on channel efficiency, Ho and Zhang (2008) conduct an experimental study and demonstrate that a two-part tariff might yield different efficiency results than a quantity-discount contract in practice. The result stems from varying degrees of risk aversion and rationality levels of real-life agents. The study concludes that channel efficiency decreases with the risk aversion level of the agents. Our analytical model leads to a similar conclusion where risk aversion causes higher degrees of departure from coordination. However, our modeling approach offers a solution to this phenomenon by augmenting the proposed pricing scheme with crop insurance, thereby eliminating the inefficiencies stemming from risk aversion. Lee et al. (2013) examine the impact of quality uncertainty and conclude that revenue sharing and buy-back contracts fail to coordinate the supply chain when the product quality is uncertain. Their study does not involve any incentives for improving quality, and the quality of manufacturer is fixed. In our problem, however, the farmer's investment in quality determines the final product's quality, and consequently, market price. Ma et al. (2013) investigate channel coordination in a two-stage supply chain motivated by the medical device industry. Demand is influenced by the retailer's sales effort and manufacturer's quality improvement efforts. They find that using the traditional two-part tariff contract alone cannot coordinate the supply chain, and propose an innovative contract in which the manufacturer shares the cost of marketing effort and the retailer shares the cost of quality effort in production. The characteristics of the motivating application, and consequent model, are quite different from ours. Their model captures a quality-demand relationship whereas our model captures a quality-price relationship. In addition, they take the perspective of a seller setting terms for a buyer, whereas we take the opposite view of a buyer setting terms for a seller.

Supply uncertainty is widely examined in the operations management literature using a stochastically proportional yield. Yano and Lee (1995) provide an extensive review, and Jones et al. (2001) exemplify its use in agricultural settings. There is a growing literature that examines price and quantity decisions under supply uncertainty. These publications include Li and Zheng (2006), Tang and Yin (2007), Kazaz and Webster (2011, 2015), and Kazaz et al. (2016). However, these studies focus on a single firm's decisions, and ignore the dynamics between a producer (farmer) and a buyer (processor and retailer). Our paper contributes to this literature by examining coordination within the buyer-seller setting, and by incorporating the pricing decision from a cooperative's perspective.

In operations and supply chain management, quality variations are often examined in the context of production processes that manufacture multiple products in a single production run. These studies are referred to as co-production systems. The studies that examine quality variations within co-production systems include the following publications: Bitran and Dasu (1992), Bitran and Gilbert (1994), Nahmias and Moinzadeh (1997), Bassok et al. (1999), Hsu and Bassok (1999), Tomlin and Wang (2008), Öner and Bilgiç (2008), Bansal and Transchel (2014), and Noparumpa et al. (2015, 2016a, 2016b). While these studies focus on quantity decisions such as downward substitution under quality variations, our paper focuses on the incentives for improving the quality of a single product, contributes to this literature by incorporating the pricing decision as a lever to incentivize the farmer in his efforts to improve quality.

3. Model

Prior to and during the growing season, the farmer chooses the amount of investment in crop quality, which we denote as $x \geq 0$. The relationship between the amount of investment and the quality of harvested crop is highly predictable. The price of olive oil increases in the crop's quality, which in turn depends on the farmer's investment in the cultivation process (e.g., his "effort"). The relationship between effort and quality is governed by a positive and strictly concave-increasing and differentiable quality function $q(x)$. We normalize the lowest quality level to 1, i.e., $q(0) = 1$. The farmer's cost per unit of input (e.g., an olive tree) is $c + ax$. The cost function accounts for a farmer's cost at the lowest quality effort (c) and the sensitivity of cost to a farmer's quality effort (a). We note that the concave structure of $q(x)$ reflects diminishing returns to investments in quality observed in practice.

The output quantity per unit of input is unpredictable due to variation in sunshine, temperature, and rain over the growing season. The member farmers are located in the same region and experience highly similar yields. The yield per unit of input experienced by member farmers is denoted by nonnegative and continuous random variable Y with variance σ_Y^2, and expectation normalized to 1, i.e., $E[Y] = 1$.

After harvest, farmers deliver their crop to the cooperative and the olives are immediately pressed into olive oil (i.e., within 48 hours of harvest). The oil is then stored for approximately three months to allow residues to settle before it is ready for sale and consumption.

We capture the correlation between the regional yield and the international open-market price by modeling price as the sum of two random terms—one term that is independent of yield and another term that is perfectly negatively correlated with yield. The random open-market price, which is proportional to quality, is

$$p_O(q, Y, Z) = q \times (Z - b(Y - 1)) \tag{1}$$

where Z is a continuous random variable that is independent of Y, with mean μ_Z and variance σ_Z^2. It is evident in (1) that q can be interpreted as the market value of quality, e.g., $q = 2$ is the level of quality such that price is twice that of the lowest quality price. Note that $E[p_O(q, Y, Z)] = q\mu_Z$ and $V[p_O(q, Y, Z)] = q^2(\sigma_Z^2 + b^2\sigma_Y^2)$. The value of b, which is nonnegative, influences the degree of correlation between open-market price and yield. In particular, the correlation coefficient is

$$\rho = \frac{E\left[\left(p_O\left(q,Y,Z\right) - q\mu_Z\right)\left(Y-1\right)\right]}{\sigma_{p_O}\sigma_Y} = \frac{-1}{\left(1+\left(\dfrac{\sigma_Z}{b\sigma_Y}\right)^2\right)^{1/2}}. \tag{2}$$

If $b = 0$, then $\rho = 0$. Correlation becomes more negative as b increases. Our price model defined in (1) provides flexibility in the specification of correlated random price and yield (via independent random variables Y and Z and parameter b) while featuring analytic tractability.

The cooperative pays the farmer the random open-market price. We refer to $p_O(q, y, z)$, which is the unit price paid to the farmer as a function of quality q and realizations y and z of Y and Z, as the open-market pricing policy (OMPP). This policy is what is currently used at Tariş.

The farmer's random profit per unit of input is the product of yield and price per unit of output less the cost per unit of input, i.e.,

$$\tilde{\pi}_O\left(x\right) = Yp_O\left(q\left(x\right),Y,Z\right) - \left(c + ax\right). \tag{3}$$

A risk-averse farmer is concerned about the possibility of losing money on his harvest, which we model through a value-at-risk (VaR) constraint:

$$\Pr\left(\tilde{\pi}_O\left(x\right) \le -\beta\right) \le \alpha. \tag{4}$$

Constraint (4) says that the probability of a loss as large as β or more must not be more than α. The value of α is small in practice (e.g., $\alpha \approx$ 5%-10%) – a risk-averse decision maker is concerned about left-tail realizations of profit. For a given α, the larger the value of β, the less risk-averse the farmer. This model of risk is consistent with farmer attitudes. The farmer's decision problem is

$$\max_x E\left[\tilde{\pi}_O(x)\right] \text{ subject to (4).}$$

The cooperative sells olive oil under its own brand, and as a much larger entity with well-established sales channels, brand recognition, and capabilities to maintain the quality of oil via temperature-controlled storage, is able to sell at a higher price than the farmer. Let m denote the cooperative's markup (net of any variable costs) over the open-market price of oil, where $m > 0$. Recall that $p_O(q, y, z) = q(z - b(y - 1))$ is the price paid to the farmer for each unit of farmer output. Thus, the cooperative's profit per unit of farmer output is $(1 + m)p_O(q, y, z) - p_O(q, y, z) = mp_O(q, y, z)$. Similarly, the cooperative's profit per unit of farmer input is $mp_O(q, y, z)y$. We assume that the cooperative is risk-neutral. For purposes of consistency of unit across farmer and cooperative profit measures (and the system), we write the cooperative's expected profit per unit of farmer input; the cooperative's expected profit per unit of input is

$$\Pi_O = E\left[mYp_O(q, Y, Z)\right].$$

4. Analysis

4.1 Optimal Expected System Profit

We begin by characterizing the optimal behavior of a farmer-cooperative system. Let R_O denote the random open-market price per unit of input at the lowest quality $q = 1$, i.e.,

$$R_O = Yp_O(1, Y, Z) = Y(Z - b(Y - 1)).$$

R_O is a positive random variable (i.e., the open-market price at the lowest quality is never negative or zero); its mean and variance are denoted μ_{R_O} and $\sigma^2_{R_O}$, respectively. The values μ_{R_O} and $\sigma^2_{R_O}$ depend on the moments of Y and Z, and parameter b (see the appendix for the derivations). For example, at any level of quality, the expected open-market revenue per input unit is less than the expected open-market revenue per output unit, i.e.,

$$q\mu_{R_O} = q(\mu_Z - b\sigma_Y^2) \le q\mu_Z. \tag{5}$$

This is due to the combination of uncertain yield and the negative correlation between yield and price per output unit, e.g., the expected revenues are equivalent if there is no correlation ($b = 0$).

The expected system profit per unit of input is

$$\Psi(x) = E\left[(1+m)q(x)R_O - (c+ax)\right] = (1+m)q(x)\mu_{R_O} - (c+ax). \tag{6}$$

The system profit is maximized at effort

$$x_S^* = q'^{-1}\left(\frac{a}{(1+m)\mu_{R_O}}\right) \tag{7}$$

yielding quality $q_S^* = q\left(x_S^*\right)$ (i.e., the first-order condition is $\left(1+m\right)q'\left(x_S^*\right)\mu_{R_O} - a =$ 0). The expected system profit is denoted Ψ_S^*, i.e., $\Psi_S^* = \Psi\left(x_S^*\right)$.

4.2 Farmer's Problem

Let $\pi_O(\alpha, x)$ denote the α-fractile of $\tilde{\pi}_O\left(x\right)$ and $r_O(\alpha)$ denote the α-fractile of R_O i.e.,

$$\Pr\left(\tilde{\pi}_O\left(x\right) \le \pi_O\left(\alpha, x\right)\right) = \Pr\left(R_O \le r_O\left(\alpha\right)\right) = \alpha.$$

Note that

$$E\left[\tilde{\pi}_O\left(x\right)\right] = q\left(x\right)\mu_{R_O} - \left(c + ax\right)$$

$$\pi_O(\alpha, x) = q\left(x\right)r_O\left(\alpha\right) - \left(c + ax\right).$$

Thus, the farmer's VaR constraint can be rewritten as

$$q(x)r_O(\alpha) - (c + ax) \ge -\beta. \tag{8}$$

Due to the strict concavity of $q(x)$, there are at most two values of x that satisfy (8) at equality. Let

$$x_O^- = \inf_x \left\{x : q\left(x\right)r_O\left(\alpha\right) - \left(c + ax\right) \ge -\beta\right\}$$

$$x_O^+ = \sup_x \left\{x : q\left(x\right)r_O\left(\alpha\right) - \left(c + ax\right) \ge -\beta\right\}.$$

Note that $\left\{x : q\left(x\right)r_O\left(\alpha\right) - \left(c + ax\right) \ge -\beta\right\} \ne \varnothing$; if this was not the case, then the farmer would not be in the business (i.e., no value of x satisfies the VaR constraint). With the above notation, we can rewrite the farmer's decision problem as

$$\max_{x \in \left[x_O^-, x_O^+\right]} q\left(x\right)\mu_{R_O} - \left(c + ax\right) \tag{9}$$

and the optimal decision is

$$x_O^* = \max\left\{x_O^-, \min\left\{x_O^+, x_O^o\right\}\right\}, \tag{10}$$

where

$$x_O^o = q'^{-1}\left(\frac{a}{\mu_{R_O}}\right) \tag{11}$$

is the optimal solution to the farmer's problem when the VaR constraint (4) is ignored (i.e., first-order condition is $q'\left(x\right)\mu_{R_O} - a =$ 0). The farmer, cooperative, and system expected profits at x_O^* are denoted π_O^*, Π_O^*, and Ψ_O^*.

The following proposition characterizes differences between centralized and decentralized solutions. The main result of Proposition 1 is the farmer under invests in quality and, as a consequence, system profit suffers.

Proposition 1. *If*

$$r_O(\alpha) < \mu_{R_O} \tag{12}$$

then

$$x_O^* = \min\left\{x_O^+, x_O^o\right\} \tag{13}$$

$$x_S^* > x_O^o \geq x_O^*,\ q_S^* > q_O^*,\ \Psi_S^* > \Psi\left(x_O^o\right) \geq \Psi_O^*. \tag{14}$$

In practice, it is highly likely for inequality (12) to hold. Recall that α is small (e.g., 10% or less). The inequality says that the value of the α-fractile of R_O is less than the mean of R_O. For the remainder of the paper we assume that (12) holds.

From (7), (11), and (14), we see that farmer under investment in quality relative to system optimal is at least partly due to low pricing power of the farmer relative to the cooperative, and may be exacerbated by the farmer's degree of risk aversion as measured by the value of his tolerable loss β. This observation is formalized in the following remark. Note that x_O^+ is increasing in β. Let β_O denote the farmer's VaR at $x = x_O^o$, i.e., $\beta_O = -\pi_O\left(\alpha, x_O^o\right)$.

Remark 1. *Farmer risk aversion contributes to under investment in quality if and only if $\beta < \beta_O$.*

4.3 Brand-Markup Pricing Policy

Proposition 1 shows that farmers under invest in quality, which is consistent with the belief of management at Tariş. The proposition raises the question of whether an alternative price schedule can be developed for which both the cooperative and farmer are better off, and that is relatively easy to implement. Recall that the open-market pricing policy is $p_O(q, y, z) = q(z - b(y - 1))$. Consider the following alternative pricing policy:

$$p_B(q, y, z) = (1+m)q\left(z - b\left(y-1\right)\right) - k / y \tag{15}$$

where k is a constant. We refer to price schedule $p_B(q, y, z)$ as the *brand-markup pricing policy* (BMPP) because it includes the cooperative's markup (m) that reflects the increased pricing power of the cooperative relative to the farmer. Note that the structure of $p_B(q, y, z)$ is analogous to a two-part tariff structure in a volume-based price schedule, but with quality playing the role of volume (i.e., there is a fixed part independent of q and a variable part proportional to q). It is well known that, relative to a volume-independent fixed wholesale price, two-part tariff wholesale pricing can increase system profit in a wholesaler-retailer supply chain (see, e.g., Moorthy 1987). As shown below, this insight extends to our setting.

Under BMPP, the random price per unit of input paid to the farmer for the lowest quality $q = 1$ is

$$R_B = Yp_B(1, Y, Z) = (1+m)Y\left(Z - b\left(Y-1\right)\right) - k = (1+m)R_O - k$$

with mean

$$\mu_{R_B} = (1+m)\mu_{R_O} - k,$$

variance

$$\sigma_{R_B}^2 = (1+m)^2 \sigma_{R_O}^2, \tag{16}$$

and α-fractile

$$r_B(\alpha) = (1+m) r_O(\alpha) - k.$$

The farmer's random profit per input unit is

$$\tilde{\pi}_B(x) = q(x)R_B - (c+ax) = q(x)(1+m)R_O - (c+ax) - k, \tag{17}$$

the farmer's expected profit is

$$E\left[\tilde{\pi}_B(x)\right] = q(x)(1+m)\mu_{R_O} - (c+ax) - k, \tag{18}$$

and the farmer's VaR constraint is

$$\pi_B(\alpha, x) = q(x)(1+m)r_O(\alpha) - (c+ax) - k \geq -\beta. \tag{19}$$

The cooperative's expected profit per input unit is k, i.e.,

$$\Pi_B(q) = E\left[(1+m)qR_O - qR_B\right] = k.$$

The farmer's problem is

$$\max_x E\left[\tilde{\pi}_B(x)\right] \text{ subject to (19).} \tag{20}$$

We let x_B^* denote the farmer's optimal decision. The corresponding level of quality is $q_B^* = q(x_B^*)$. The farmer, cooperative, and system expected profits at x_B^* are denoted π_B^*, Π_B^*, and Ψ_B^*. The farmer and cooperative receive fraction $1 - k/\Psi_B^*$ and k/Ψ_B^* of expected system profit, respectively.

Recall from Proposition 1 that $\Psi_S^* > \Psi_O^* (= \Pi_O^* + \pi_O^*)$. Thus, the cooperative may select a value of k in the range

$$k \in \left[\Pi_O^*, \Psi_S^* - \pi_O^*\right] \tag{21}$$

in order to assure that neither party is worse off relative to the open-market pricing policy; all of the gain due to system optimal investment goes to the farmer if $k = \Pi_O^*$, and to the cooperative if $k = \Psi_S^* - \pi_O^*$. We refer to a BMPP policy satisfying the individual rationality constraint (21) as a *viable* BMPP policy.

Notice that the farmer's marginal expected profit per input unit is identical to the system marginal expected profit per input unit (compare (18) with (6)). Thus, if the farmer's VaR constraint (19) is nonbinding, then the optimal investment in quality is

$$x_B^* = q'^{-1}\left(\frac{a}{(1+m)\mu_{R_O}}\right) = x_S^* .$$

This observation is formalized in the following remark. Let $\Psi_S^*(\alpha)$ denote the optimal system profit at fractile α.

Remark 2. *If* $\Psi_S^*(\alpha) \geq k - \beta$*, then the farmer's VaR constraint* (19) *is nonbinding under BMPP and* $x_B^* = x_S^*$*. Furthermore, if* $\Psi_S^*(\alpha) < \Pi_O^* - \beta$ *, then the farmer's VaR constraint* (19) *is binding under any viable BMPP policy.*

While BMPP aligns the incentives of an expected-profit-maximizing farmer with the system as a whole, it exposes the farmer to more risk. For example, from (16) and (17) it is clear that for any given *x*, the farmer experiences greater volatility in profit under BMPP than OMPP, i.e.,

$$V\left[\tilde{\pi}_O(x)\right] = q(x)^2 \sigma_{R_O}^2$$

$$V\left[\tilde{\pi}_B(x)\right] = (1+m)^2 q(x)^2 \sigma_{R_O}^2 = (1+m)^2 V\left[\tilde{\pi}_O(x)\right].$$

Indeed, it is possible (depending on parameter values) that the farmer and/or cooperative will be worse off under BMPP than OMPP. Thus, to exploit the power of BMPP, we consider the characteristics of crop insurance that mitigate the effects of farmer risk aversion.

As an aside, we note that early in our analysis we investigated a series of more complex pricing policies for mitigating the negative effect of risk aversion on a farmer's quality investment, i.e., via the inclusion of an additional policy parameter under BMPP. However, such a price schedule depends on estimates of farmer risk aversion (β), farmer efficiency (a), and the probability distribution of R_O. In practice, there is variation in risk aversion and efficiency among farmers. The dependency on farmer-specific parameters (β and a) restricts the potential gain in profits from the policy. Furthermore, due to variation in β and a, even if these parameters (and the probability distribution) can be accurately estimated, there may not exist a price schedule under which member farmers and the cooperative are not worse off compared to OMPP (i.e., a price schedule that satisfies individual rationality constraints may not exist for the given range of β and a). Our discussions with management at Tariş reinforced the importance of simplicity of implementation and robustness (i.e., not sensitive to estimation errors) in a pricing policy. These discussions also showed an openness to use crop insurance for mitigating farmer risk aversion.

4.4 Mitigating Farmer Risk via Crop Insurance

Recall that the farmer's tolerable VaR (at probability α) is β. Consider an insurance policy that limits the farmer's loss per unit of input to no more than β, and suppose the cooperative pays the farmer according to a BMPP price schedule.

The payoff under the insurance policy depends on the quality of the crop, and so with slight abuse of notation, we let $\tilde{\pi}_B(q,k)$ denote the farmer's random profit per input unit at quality q. The random payoff for insurance policy (q, k, β) is

$$\tilde{p}(q,k,\beta) = \max\{-\tilde{\pi}_B(q,k) - \beta, 0\}$$

and the expected payoff is

$$\overline{p}(q,k,\beta) = E\left[\max\{-\tilde{\pi}_B(q,k) - \beta, 0\}\right].$$

(The expressions are the same for OMPP, except $\tilde{\pi}_O$ replaces $\tilde{\pi}_B$. We focus our analysis on BMPP.)

The above insurance policy is relatively simple to implement because, other than the cooperative's price schedule (which is publicly available), the expected payoff only requires knowledge of the probability distribution of the random open-market price per unit of input R_O, for which there is extensive historical data (see Figure 1). An insurance contract only requires the farmer to specify his tolerable loss β.

As a risk-neutral entity, the cooperative can provide insurance to farmers with the insurance premium equal to the expected payoff $\overline{p}(q,k,\beta)$ without affecting its expected profit. Our conversations with management at Tariş indicate this is their preference (e.g., as opposed to insurance offered through a third-party provider that will extract some surplus). In fact, Tariş has begun to offer insurance of this type to farmers in a small village of olive growers on a pilot basis. This insurance policy in combination with BMPP results in system optimal investment in quality by the farmer.

We let BMPP/I denote the BMPP pricing policy supplemented by insurance where k satisfies (21). We use subscript B/I to denote decisions and expected profits under policy BMPP/I in the following remark.

Remark 3. *Under* BMPP/I: $x^*_{B/I} = x^*_S > x^*_O$, $q^*_{B/I} = q^*_S > q^*_O$, $\pi^*_{B/I} \geq \pi^*_O$, $\Pi^*_{B/I} \geq \Pi^*_O$, $\Psi^*_{B/I} = \Psi^*_S > \Psi^*_O$.

4.5 Quadratic Cost of Quality

We specify a functional form for the relationship between cost and quality in order to investigate relationships among decisions and profits in more detail. Tariş does not collect data on the quality-cost relationship. However, drawing on knowledge of the industry, management at Tariş helped us select a quadratic quality cost function. This function captures diminishing marginal return to quality in a plausible manner in the view of management and affords some tractability. Quality as a function of effort x is

$$q(x) = 1 + x^{1/2} \tag{22}$$

and cost as a function of quality is

$$C(q) = c + a(q-1)^2$$

(obtained by inverting $q(x)$ and substituting into cost $c + ax$).

The following proposition shows relationships among optimal decisions and system profits given the quality function defined in (22). Note that expected system profit per unit of input with no investment in quality is

$$\Psi(0) = (1+m)\mu_{R_O} - c \tag{23}$$

(see (6)). We refer to $\Psi(0)$ as *base profit*.

Proposition 2.

$$x_O^* \le x_O^{\circ} = \left(\frac{\mu_{R_O}}{2a}\right)^2$$

$$q\left(x_O^*\right) \le q\left(x_O^{\circ}\right) = 1 + \frac{\mu_{R_O}}{2a} \tag{24}$$

$$\Psi\left(x_O^*\right) \le \Psi\left(x_O^{\circ}\right) = \Psi(0) + \frac{1+2m}{(1+m)^2}\left[\frac{\left((1+m)\mu_{R_O}\right)^2}{4a}\right] \tag{25}$$

$$x_B^* \le x_{B/I}^* = x_S^* = \left(\frac{(1+m)\mu_{R_O}}{2a}\right)^2 = (1+m)^2\, x_O^{\circ}$$

$$q\left(x_B^*\right) \le q\left(x_{B/I}^*\right) = 1 + (1+m)\frac{\mu_{R_O}}{2a} = q\left(x_O^{\circ}\right) + m\frac{\mu_{R_O}}{2a} \tag{26}$$

$$\Psi\left(x_B^*\right) \le \Psi\left(x_{B/I}^*\right) = \Psi(0) + \left[\frac{\left((1+m)\mu_{R_O}\right)^2}{4a}\right] \tag{27}$$

$$\frac{\Psi\left(x_{B/I}^*\right) - \Psi(0)}{\Psi\left(x_O^*\right) - \Psi(0)} \ge \frac{\Psi\left(x_{B/I}^*\right) - \Psi(0)}{\Psi\left(x_O^{\circ}\right) - \Psi(0)} = 1 + \frac{m^2}{1+2m} \ge \frac{\Psi\left(x_{B/I}^*\right)}{\Psi\left(x_O^{\circ}\right)}. \tag{28}$$

Expressions (23) – (28) help illuminate how cost terms (a and c) and revenue terms (μ_{R_O} and m) interact to influence the degree to which BMPP/I improves system profit over OMPP. Suppose that the VaR constraint is nonbinding under OMPP. Then the gain in BMPP/I profit over base profit is at least $\frac{m^2}{1+2m}\times 100$ percent more than the gain in OMPP profit over base profit; the percentage is determined solely by markup m. The reason is the roles that farmer's quality efficiency (a) and the open market price (μ_{R_O}) play in the farmer's optimal decisions are identical under BMPP/I and OMPP with nonbinding VaR constraint (cf. (25) and (27)). The values of a and μ_{R_O} influence how much BMPP/I profit increases over base profit, and thus conjunction with *c*, influence the overall ratio $\Psi\left(x_{B/I}^{*}\right)/\Psi\left(x_{O}^{o}\right)$. The next proposition presents comparative static results for $\Psi\left(x_{B/I}^{*}\right)/\Psi\left(x_{O}^{o}\right)$.

Proposition 3. *The value of* $\Psi\left(x_{B/I}^{*}\right)/\Psi\left(x_{O}^{o}\right)$ *is decreasing in a and is increasing in c*; $\Psi\left(x_{B/I}^{*}\right)/\Psi\left(x_{O}^{o}\right)$ *is increasing in* μ_{R_O} *if and only if*

$$\frac{\mu_{R_O}}{c} \geq \frac{2}{1+m}, \tag{29}$$

and is increasing in m if

$$\frac{\mu_{R_O}}{c} \geq \frac{2}{1+m}.$$

We see that the gain in system profit from BMPP/I over OMPP when the VaR constraint is not binding is greater for an efficient farmer (small *a*) than an inefficient farmer (large *a*). This is a consequence of the convexity of the quality cost function, which causes the quality difference $q\left(x_{B/I}^{*}\right)-q\left(x_{O}^{o}\right)$ to be decreasing in *a*. On the other hand, if the cost of achieving the lowest quality (*c*) increases, then the percentage gain in system profit increases. However, this is only because all profits shrink as *c* increases; the absolute difference in system profit $\Psi\left(x_{B/I}^{*}\right)-\Psi\left(x_{O}^{o}\right)$ is independent of *c*.

The effect of increasing μ_{R_O} and *m* is more nuanced because increases in these parameters (1) inflate both $\Psi\left(x_{B/I}^{*}\right)$ and $\Psi\left(x_{O}^{o}\right)$, which puts negative pressure on the percentage gain, and (2) increase the quality difference $q\left(x_{B/I}^{*}\right)-q\left(x_{O}^{o}\right)$, which puts positive pressure on the percentage gain. For the case of μ_{R_O}, a simple inequality delineates the boundary between where negative or positive pressure dominates. This inequality is a sufficient condition for $\Psi\left(x_{B/I}^{*}\right)/\Psi\left(x_{O}^{o}\right)$ to be increasing in markup (*m*), e.g., if the profit gain is increasing in μ_{R_O}, then it is assured to be increasing in *m*, but not vice-versa. The reason for this result is related to what we see in (28). To clarify, let Ω_y denote the set of parameter values such that $\frac{\partial}{\partial y}\left[\frac{\Psi\left(x_{B/I}^{*}\right)}{\Psi\left(x_{O}^{o}\right)}\right] \geq 0$ for $y \in \left\{\mu_{R_O}, m\right\}$. In (28) we see that increases in μ_{R_O} do not increase the profit gain relative to base profit, but *m* does, and this additional leverage explains why $\Omega_{\mu_{R_O}} \subset \Omega_m$. A precisely defined parameter region governing the sign of $\frac{\partial}{\partial m}\left[\frac{\Psi\left(x_{B/I}^{*}\right)}{\Psi\left(x_{O}^{o}\right)}\right]$ (e.g., as opposed to a sufficient condition) is complex and not insightful.

5. Estimating the Value of BMPP/I in Practice

This section presents the financial impact from using our proposed pricing policy BMPP with insurance (BMPP/I) over the current OMPP practice at Tariş. We explain how we calibrate our model in Section 5.1.

Some farmers are more efficient than others (i.e., the cost to improve quality is not the same for all farmers). In Section 5.2, we examine quality levels and corresponding percentage improvement in system profit due to BMPP/I over a range of farmer efficiencies. Our analysis illustrates how decisions and profits are influenced by the pricing policy and farmer efficiency, and allows us to estimate the profit improvement from BMPP/I.

In contrast with farmer efficiency, comparative statics for expected open-market price and brand markup are not monotonic in general (see Proposition 3). In Section 5.3, we examine the impact of changes in these parameters in our calibrated model.

5.1 Model Calibration

We use data obtained from Tariş to estimate parameters and probability distributions in our model. We begin by presenting the relevant parameter values with a brief description of the data used to estimate their values. We then present a series of numerical results that illustrate the impact of a BMPP/I policy compared to OMPP.

We express all cost and revenue terms in US$. The input unit is the quantity that yields one liter of olive oil on average. The data for the open-market olive oil prices are obtained from the Mercado de Futuros del Aceite de Oliva, which is the olive oil futures market known as MFAO. The data features prices for EVOO over the last 30 years, from February 1986 to February 2016 (see Figure 1). We use this data in order to estimate the parameters of random variable Z; we find $\mu_Z = 3.8$, $\sigma_Z^2 = 0.6$. We describe the pdf of Z as uniform between $[3.8 - 3/(5)^{1/2}, 3.8 + 3/(5)^{1/2}]$.

The data for random yield are provided by Tariş, and include yield realizations from 2007 to 2015. We use these data as the distribution of yield random variable Y (i.e., the pdf of Y is the histogram of historical realizations); $\mu_Y = 1$ and $\sigma_Y^2 = 0.5$, respectively. Using the data between 2007 and 2015 for yield and open market olive oil prices, we estimate parameter b (sensitivity of open-market price to regional yield) from the observed correlation ρ and the relationship between b and ρ given in (2). The correlation coefficient ρ is estimated to be –65.7%, which implies sensitivity parameter $b = 1.1$. With these parameters and distributions, the expected open market price at the lowest quality level is $\mu_{R_O} = \mu_Z - b\sigma_Y^2 = 3.8 - 0.55 = 3.25$, and the fractile of R_O at $\alpha = 0.10$ is $r_O(0.10) = 1.87$.

The brand markup parameter m is provided by Tariş, which is the average markup that is net of all variable costs, including bottling, packing, distribution, over all of the oleic acidity levels in the premium category (i.e., oleic acidity ≤ 2%); m = 0.8. Tariş management estimates the farmer cost per input unit at the lowest quality level to be c = \$2.9.

Recall that the open market price and the retail price of olive oil are proportional to value of q. Figure 2 illustrates the relationship between cost of the farmer's effort to improve quality and the corresponding percentage increase in olive oil price relative to the price for the lowest quality olive oil. We shared versions of Figure 2 (computed at different values of parameter a) with Tariş management in order to identify a value of a. Their knowledge and experience suggests that a = 2.2.

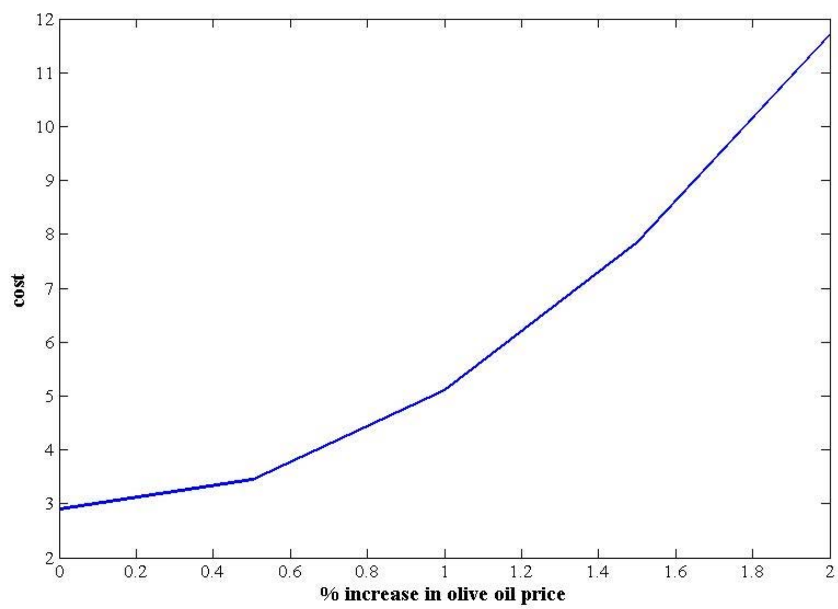

Figure 2. Cost as a function of % increase in the open market olive oil price over the price at the lowest quality, i.e., % price increase = q – 1. The parameter values are c = 2.9, a = 2.2.

Our work has prompted Tariş to offer insurance to farmers from a small village in the Altınoluk region of Edremit Bay on a pilot basis. Our risk parameters draw on knowledge from this pilot program. The most widely requested insurance coverage corresponds to loss amount β = 0.8, with probability estimated at α = 0.10.

5.2 Impact of BMPP/I on Quality and Profit for Different Farmer Efficiencies

Figure 3 shows the impact of farmer efficiency on the optimal quality under three settings: (1) optimal quality under OMPP when farmer risk aversion is ignored, $q\left(x_O^{\circ}\right)$ (equivalently, tolerable loss $\beta \geq \beta_O$); (2) optimal quality under OMPP incorporating farmer risk aversion with the VaR constraint, $q\left(x_O^{*}\right)$; (3) optimal quality under BMPP/I, $q\left(x_{B/I}^{*}\right)$. Lower values of a represent cost-efficient farmers whereas higher values of a correspond to inefficient farmers. Figure 3 illustrates relationships in Proposition 2, and the significance of the relationships in a real-world setting. For example, optimal investment in quality is decreasing with farmer inefficiency. The negative relationship between farmer inefficiency and quality is evident in (24) and (26) for the case of $q\left(x_O^{\text{o}}\right)$ and $q\left(x_{B/I}^{*}\right)$. In Figure 3 we see the same pattern in $q\left(x_O^{*}\right)$ – that the negative relationship is unaffected by risk aversion. Second, risk aversion causes the farmer to decrease the level of quality investment under the OMPP policy (see (24)). Third and most important, Figure 3 illustrates the magnitude of quality improvement under BMPP/I (see (26)), e.g., approximately 50% increase in quality over the range of farmer efficiencies. BMPP/I leads to a significantly higher quality at every level of farmer efficiency than the presently in place OMPP policy (with and without risk aversion). This third observation is critical from the perspective of Tariş because it addresses the common problem of under-investment in quality.

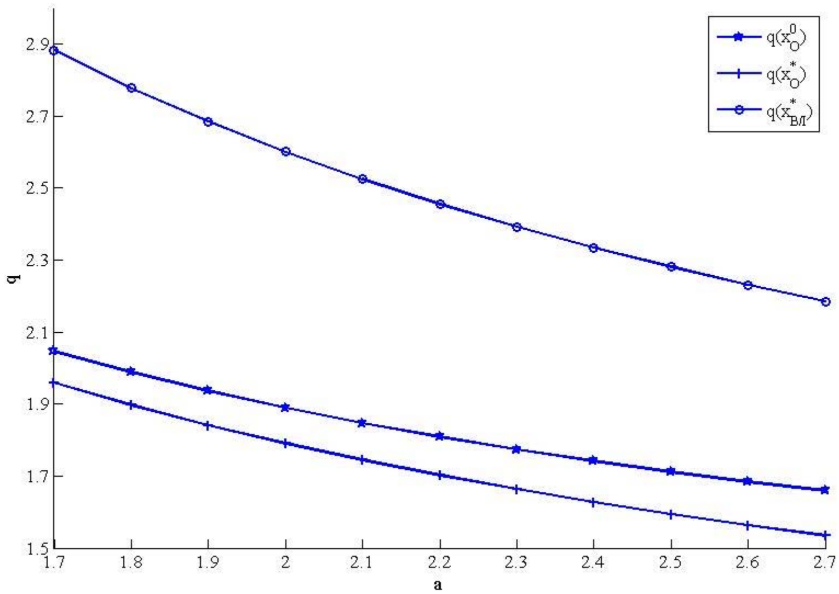

Figure 3. Optimal quality levels under OMPP with risk-neutral and risk averse farmers, and under BMPP/I as farmer inefficiency (*a*) increases.

Figure 4 shows the magnitude of improvement in system profit from BMPP/I relative to the current OMPP policy for both risk-neutral and risk-averse farmers. If the farmer's VaR constraint is nonbinding, then the gain in system profit ranges between 12% and 15%, with the percentage gain decreasing in farmer inefficiency. From (26) we know that the gain is greater when risk aversion constrains the farmer's investment in quality. Figure 4 shows a profit gain of approximately 18% under risk aversion over the range of efficiency levels. Interestingly, the percentage gain is not decreasing in farmer inefficiency as it is when the farmer is risk neutral. This is because an inefficient farmer has more to lose from effort to improve quality (due to higher cost), which translates into higher cutbacks in quality effort to satisfy the risk constraint (see the increasing gap between $q\left(x_O^{o}\right)$ and $q\left(x_O^{*}\right)$ as *a* increases, both in absolute and, especially percentage, measures). This effect of increasing farmer inefficiency on risk is further illustrated in Figure 5. The top curve shows the farmer's VaR if he ignores his VaR constraint and optimally invests in quality. Note that VaR is increasing in inefficiency. To satisfy his VaR constraint, the farmer reduces his investment in quality, which results in the lower curve with VaR equal to its upper limit of $\beta = 0.8$.

We note that Figure 4 also exposes the gain from crop insurance with no change in the pricing policy. The percentage gain in OMPP profit by eliminating the negative effect of risk aversion through crop insurance ranges from 2.6% (= 1.18/1.15 – 1) for an efficient farmer (*a* = 1.5) to 5.4% (= 1.18/1.12) for an inefficient farmer (*a* = 2.5). In other words, approximately 3% to 5% of the 18% gain in profit from BMPP/I can be attributed to the elimination of the binding VaR constraint, with the balance of 13% to 15% due to the alignment of farmer incentives with the system.

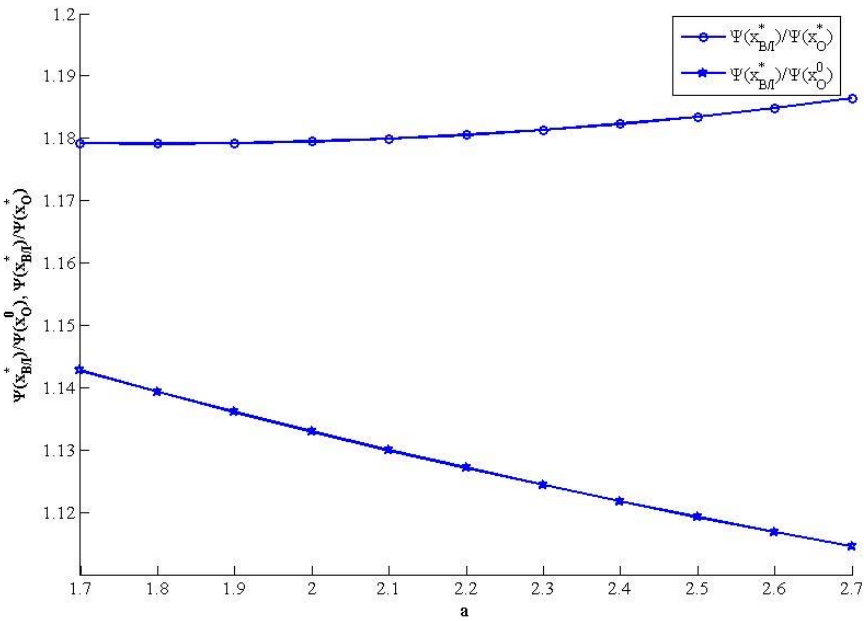

Figure 4. Ratio of BMPP/I-to-OMPP expected system profit as farmer inefficiency (*a*) increases.

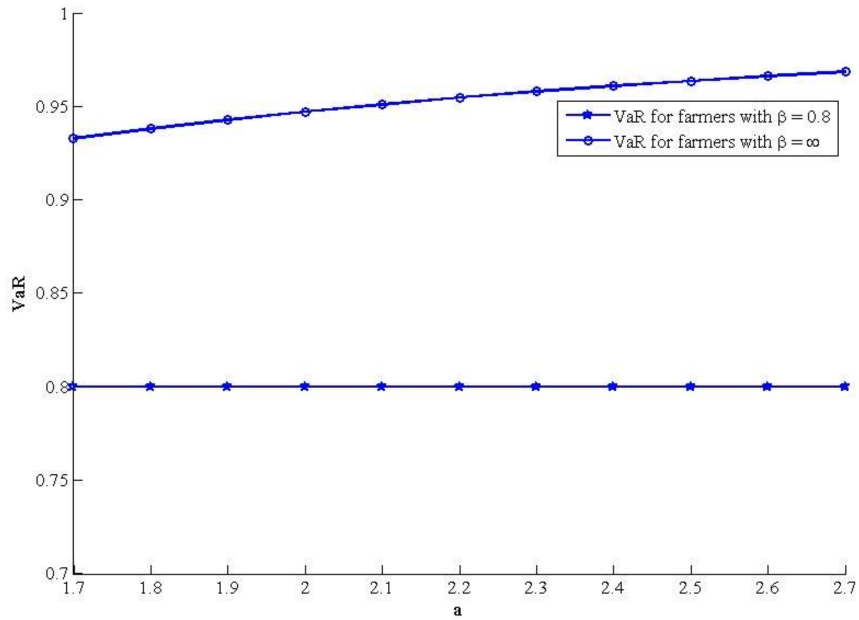

Figure 5. Value at risk for risk averse (with $\beta = 0.8$) and risk neutral (with $\beta = \infty$) farmers as farmer inefficiency (a) increases.

5.3 Impact of Changes in Expected Open-Market Price and Brand Markup

We next examine the influence of open-market price for EVOO and the cooperative's brand markup on the farmer's quality investments and system profits. Our analysis continues to use the same cost parameters. Recall that the expected open-market price for the lowest quality olive oil is $\mu_Z = 3.8$ in the time interval 2007 – 2015. Figure 6 illustrates the impact of changing open-market price on quality under OMPP (with risk-averse and risk-neutral farmers) and BMPP/I policies as the average open-market price ranges between 3.5 and 4.1. Figure 7 shows how the percentage gain in system profit from BMPP/I changes as the average open-market price changes. From (24) and (26), and the fact that μ_{R_O} is increasing in μ_Z (see (5)), we know that $q\left(x_O^{\mathrm{o}}\right)$ and $q\left(x_{B/I}^*\right)$ are increasing in open-market price. Figure 6 illustrates this behavior, and shows that the risk-constrained quality, $q\left(x_O^*\right)$, is increasing as well. In addition, we see how a sufficiently high open-market price (e.g., $\mu_Z \geq 4.1$) reduces a farmer's risk under OMPP to the point where the VaR constraint becomes nonbinding. This effect also appears in Figure 7 that shows the gain in profit from BMPP/I; the percentage gain is decreasing in μ_Z if a farmer is risk averse up to the point where the VaR constraint is nonbinding ($\mu_Z \approx 4.1$) because the impact of the VaR constraint on the farmer's decision gets smaller as μ_Z increases. From Proposition 3, the percentage gain for a risk-neutral farmer is decreasing in μ_Z up to $\mu_Z =$

$2c(1 + m) + b\sigma_Y^2 \approx 3.77$ (see (5) and (29)). However, the effect in Figure 7 is virtually undetectable, as $\Psi\left(x_{B/I}^*\right) / \Psi\left(x_O^{\circ}\right)$ is approximately flat.

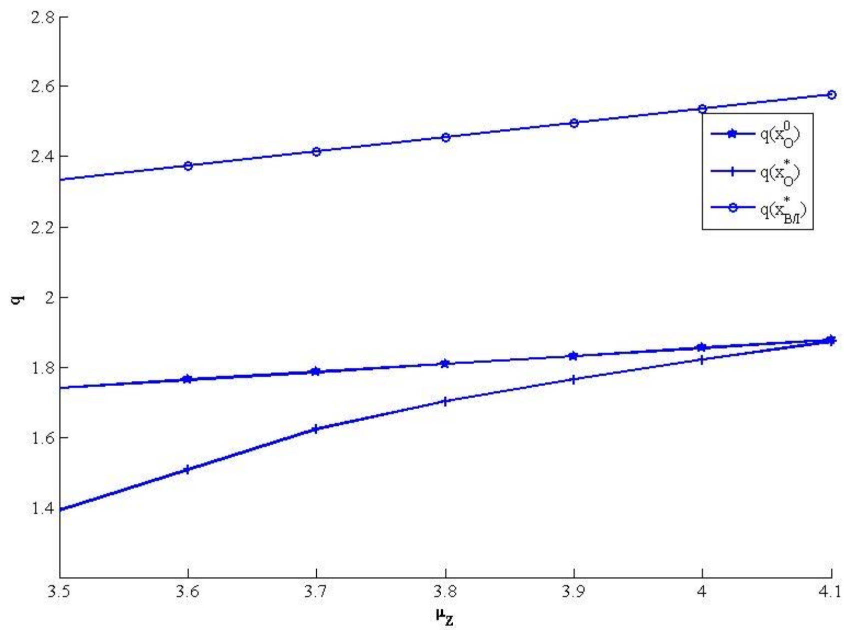

Figure 6. Optimal quality levels under BMPP/I and OMPP as average open-market price (μ_Z) increases.

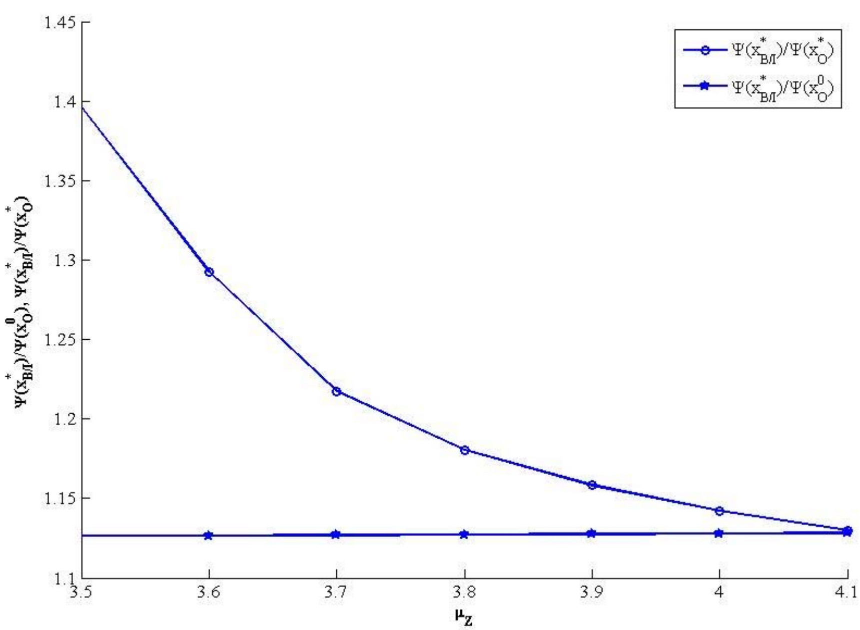

Figure 7. Ratio of BMPP/I-to-OMPP expected system profit as average open-market price (μ_Z) increases.

We next examine the impact of a change in the cooperative brand markup (*m*). Recall that quality under OMPP is unaffected by *m*, and is increasing in *m* under BMPP/I (see (24) and (26)). From Proposition 3, the percentage gain in system profit due to BMPP/I is assured to be increasing in brand markup for a risk-neutral farmer if $m \geq 2c/\mu_{R_O} - 1 \approx$ 0.79 (see sufficient condition (29)). Figure 8 shows that profit improvement from BMPP/I in our calibrated model is consistently increasing in brand markup for both risk-neutral and risk-averse farmers. It is also easy to see that in the absence of a brand markup (with *m* = 0), the expected profit under BMPP/I is equal to the expected profit under OMPP with risk-neutral farmers. This is because the optimal quality investment levels become equal in these two scenarios (see (7) and (11)). On the other hand, risk-averse farmers continue to underinvest even in the absence of a brand markup (with *m* = 0), leading to a ratio of expected profits from BMPP/I and OMPP with risk-averse farmers greater than 1. Thus, even in the absence of a brand markup, policy BMPP/I generates a higher expected profit in practice than the presently-used OMPP policy.

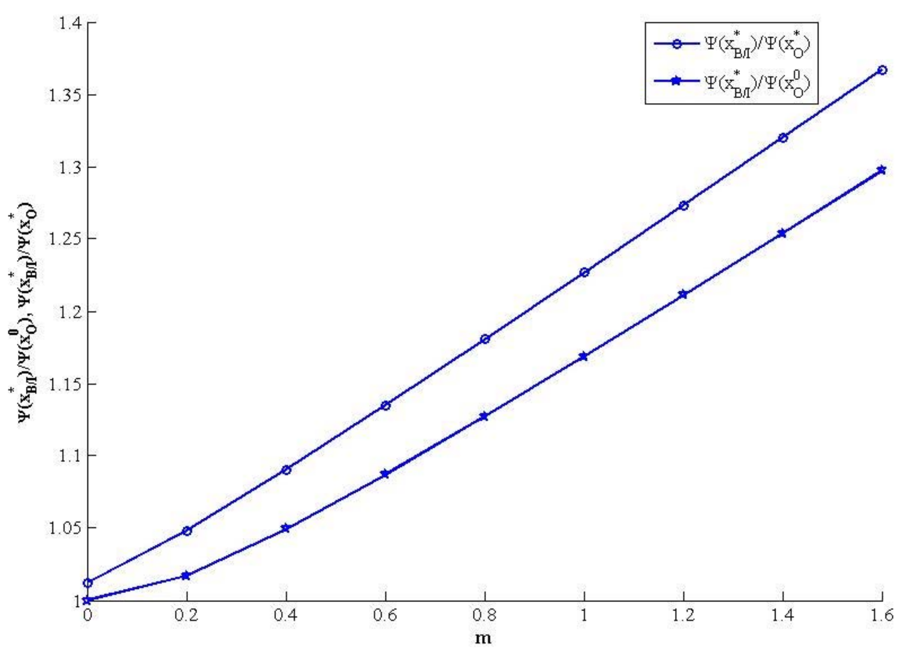

Figure 8. Ratio of BMPP/I-to-OMPP expected system profit as brand markup (*m*) increases

6. Conclusions

We consider an agricultural cooperative that sets the prices it will pay to its member farmers for different levels of crop quality. Our work is motivated by Tariş, the second largest EVOO producer in Turkey. Tariş became an independent entity without government support in year 2000. The change has prompted greater emphasis on improvements that help assure the long-term financial stability of the cooperative.

Tariş currently pays farmers according to EVOO prices in the open market (i.e., OMPP). Management believes that farmers under-invest in the quality of the crop. Our analysis confirms that the management's belief regarding farmers' under-investment in quality is true in practice, and that it is a consequence of the cooperative's higher pricing power and lower sensitivity to risks from yield and open-market price volatility.

We describe and analyze a new pricing policy (i.e., BMPP) that aligns the risk-neutral farmer's incentives with the system. BMPP introduces greater volatility in farmer profit compared to OMPP, but when augmented with crop insurance, incentivizes farmers to optimally invest in quality, leading to higher system profit with both farmer and cooperative better off. Using industry data, we find the percentage gain in system profit due to BMPP to be ranging from 10% to 20%. Approximately 20% to 30% of the gain stems from mitigating farmer risk aversion (via crop insurance) with the balance of 70% to 80% coming from the alignment of farmer incentives with the system.

We next offer an interpretation of BMPP that serves to both reinforce the intuition into what drives differences between BMPP and OMPP performance and to illuminate the specifics of BMPP implementation. Recall that under OMPP, the quality-dependent price paid to the farmer matches what the farmer would receive in the open market, which is a lower price than what the cooperative can fetch. Under BMPP, the cooperative pays the farmer its quality-dependent retail price per unit (net of its variable costs), then subtracts a constant that is independent of quality and yield. In essence, the cooperative is putting itself in a position that is akin to being a landowner – it's as if the cooperative receives a rent per tree, which is the portion of the price schedule that is independent of quality and yield, and allows the farmer to invest in the land to maximize his payoff. The "rent" is set so that the cooperative is no worse off (compared to OMPP profit), and because the farmer is making wiser quality decisions, the farmer is better off. The farmer receives the full retail price for EVOO (i.e., the open-market price inflated by the cooperative's brand markup), and implementation boils down to determining an agreeable rent per tree.

Building on the success from offering insurance in a small region, we recommend that Tariş test the proposed brand markup pricing policy with insurance in a larger region as an extended pilot study. Under BMPP, farmers pay a "premium membership fee in return for full EVOO profit" (e.g., price paid to the farmer per liter of EVOO is 80% more than under OMPP). In order to determine the farmer membership fee, the cooperative may identify what it perceives as a fair and reasonable profit from the region (e.g., to continue in invest in improvements needed for long-term financial viability with sufficient reserve to weather swings in the market). Dividing this value by the number of trees in the region yields a "fee-per-tree," which is multiplied by number of trees on a farm to yield the farmer's annual membership fee, i.e., the farmer pays a membership fee according to the size of his farm. Our proposal is under discussion at Tariş.

There are additional benefits associated with offering insurance, and with complementing BMPP with insurance. The cooperative can collect detailed information about what farmers do in their quality improvement efforts. This would enable the cooperative to educate its member farmers about the state-of-the-art farming techniques. It would also lead to a more transparent environment where both the cooperative and its members share information about the costs and revenues in growing olives and producing olive oil. Such information-sharing transparency would result in a stronger dependence and reliance between all parties, and would enable both parties to form common objectives.

We believe that this new pricing policy BMPP/I is particularly attractive for those farmers who focus on organic farming using biodynamic methods to improve fruit quality (olives), soil fertility and yields. Certain villages and olive growth regions are marked with certification from the Chamber of Commerce for biodynamic practices. The implementation at these regions can serve as a pilot study for assessing BMPP/I in practice.

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Appendix

Expressing μ_{R_O} and $\sigma^2_{R_O}$ in terms of model primitives

The values μ_{R_O} and $\sigma^2_{R_O}$ depend on moments of Y and Z. Let f_Y and f_Z denote the pdfs of Y and Z.

$$\mu_{R_O} = E[Y(Z - b(Y - 1))] = E[Z] - bE[Y^2 - Y] = E[Z] - b(E[Y^2] - 1) = \mu_Z - b\sigma^2_Y \tag{30}$$

$$E[R_O^2] = \iint y^2\left(z^2 - 2bz\left(y-1\right) + b^2\left(y^2 - 2y + 1\right)\right) f_Y\left(y\right) f_Z\left(z\right) dydz$$

$$= E[Y^2]E[Z^2] - 2bE[Z](E[Y^3] - E[Y^2]) + b^2(E[Y^4] - 2E[Y^3] + E[Y^2])$$

$$\sigma^2_{R_O} = E\left[R_O{}^2\right] - \mu^2_{R_O} .$$

Proof of Proposition 1. We first prove the result in (13). Recall that x^{o}_O the farmer investment in quality that maximizes expected profit, i.e., $q'\left(x^{\text{o}}_O\right) = \dfrac{a}{\mu_{R_O}}$. The lower bound on quality investment is zero, and we assume without loss of generality that this bound is set low enough that negative investment in quality is never economically desirable (e.g., x can be interpreted as the increase in quality investment above the lowest viable level among the population of member farmers), i.e., $x^{\text{o}}_O \geq 0$. The result clearly holds if $x^-_O \leq 0$, i.e., $x^-_O < x^{\text{o}}_O$ and $x^-_O \leq x^+_O$ (by definition) and thus $\max\left\{x^-_O, \min\left\{x^+_O, x^{\text{o}}_O\right\}\right\} = \min\left\{x^+_O, x^{\text{o}}_O\right\}$. Similarly, the result holds if $x^-_O = x^+_O$

Suppose that $0 < x^-_O < x^+_O$, which is the only remaining possibility to consider. The values x^-_O and x^+_O are the points at which the following two curves intersect (due to continuity of $q(x)$):

$$\text{LHS}(x) = q(x)r_O(\alpha) = ax + c - \beta = \text{RHS}(x).$$

From the concavity of $q(x)$, it follows that LHS(x) crosses RHS(x) from below to above at $x = x^-_O$ (and if x^+_O is finite so that the curves cross again, then LHS(x) crosses RHS(x) from above to below at $x = x^+_O$). Thus,

$$q'\left(x^-_O\right) r_O\left(\alpha\right) \geq a$$

$$\Rightarrow \quad q'\left(x^-_O\right) > \frac{a}{r_O\left(\alpha\right)}$$

$$> \frac{a}{\mu_{R_O}} \qquad \text{(due to (12))}$$

$$= q'\left(x^{\text{o}}_O\right)$$

$$\Rightarrow \quad x^-_O < x^{\text{o}}_O \qquad \text{(due to the concavity of } q(x)\text{)}.$$

Therefore, $x_O^* = \min\left\{x_O^+, x_O^{\text{o}}\right\}$, which is (13). The results in (14) follow from the concavity of $q(x)$ and the expressions for x_O^* and x_S^*. □

Proof of Proposition 2. Note that $q'(x) = \dfrac{1}{2x^{1/2}}$, and thus

$$q'\left(x_O^{\text{o}}\right) = \frac{1}{2x_O^{\text{o}\,1/2}} = \frac{a}{\mu_{R_O}} \Rightarrow x_O^{\text{o}} = \left(\frac{\mu_{R_O}}{2a}\right)^2$$

$$q'\left(x_S^*\right) = \frac{1}{2x_S^{*1/2}} = \frac{a}{(1+m)\mu_{R_O}} \Rightarrow x_S^* = \left(\frac{(1+m)\mu_{R_O}}{2a}\right)^2.$$

The remaining results can be obtained through algebra (we omit the details) and, with respect to (28), by observing

$$\frac{\Psi\left(x_{B/I}^*\right) - \Psi(0)}{\Psi\left(x_O^{\text{o}}\right) - \Psi(0)} = \frac{\Psi\left(x_{B/I}^*\right)}{\Psi\left(x_O^{\text{o}}\right)}\left(\frac{1-\Psi(0)/\Psi\left(x_{B/I}^*\right)}{1-\Psi(0)/\Psi\left(x_O^{\text{o}}\right)}\right) \geq \frac{\Psi\left(x_{B/I}^*\right)}{\Psi\left(x_O^{\text{o}}\right)}. \ □$$

Proof of Proposition 3. Let

$$y = \frac{\left((1+m)\mu_{R_O}\right)^2}{4a\left[(1+m)\mu_{R_O} - c\right]} > 0$$

$$z = \frac{1+2m}{(1+m)^2} \in (0, 1).$$

Then

$$\frac{\Psi\left(x_{B/I}^*\right)}{\Psi\left(x_O^{\text{o}}\right)} = \frac{1+y}{1+yz}$$

$$\frac{\partial y}{\partial c} = \frac{1}{4a}\left(\frac{(1+m)\mu_{R_O}}{\left[(1+m)\mu_{R_O} - c\right]}\right)^2 > 0$$

$$\frac{\partial y}{\partial a} = -\frac{\left((1+m)\mu_{R_O}\right)^2}{4a^2\left[(1+m)\mu_{R_O} - c\right]} < 0$$

$$\frac{\partial y}{\partial \mu_{R_O}} = \left(\frac{4a(1+m)^2\mu_{R_O}}{\left(4a\left[(1+m)\mu_{R_O} - c\right]\right)^2}\right)\left[(1+m)\mu_{R_O} - 2c\right] \geq 0 \Leftrightarrow \frac{\mu_{R_O}}{c} \geq \frac{2}{1+m}.$$

Therefore,

$$\frac{\partial}{\partial c}\left[\frac{\Psi\left(x_{B/I}^{*}\right)}{\Psi\left(x_{O}^{\text{o}}\right)}\right]=\frac{\partial}{\partial y}\left[\frac{\Psi\left(x_{B/I}^{*}\right)}{\Psi\left(x_{O}^{\text{o}}\right)}\right]\frac{\partial y}{\partial c}>0$$

$$\frac{\partial}{\partial a}\left[\frac{\Psi\left(x_{B/I}^{*}\right)}{\Psi\left(x_{O}^{\text{o}}\right)}\right]=\frac{\partial}{\partial y}\left[\frac{\Psi\left(x_{B/I}^{*}\right)}{\Psi\left(x_{O}^{\text{o}}\right)}\right]\frac{\partial y}{\partial a}<0$$

$$\frac{\partial}{\partial \mu_{R_O}}\left[\frac{\Psi\left(x_{B/I}^{*}\right)}{\Psi\left(x_{O}^{\text{o}}\right)}\right]=\frac{\partial}{\partial y}\left[\frac{\Psi\left(x_{B/I}^{*}\right)}{\Psi\left(x_{O}^{\text{o}}\right)}\right]\frac{\partial y}{\partial \mu_{R_O}}\geq 0 \Leftrightarrow \frac{\mu_{R_O}}{c}\geq\frac{2}{1+m}.$$

For the sign of $\frac{\partial}{\partial m}\left[\frac{\Psi\left(x_{B/I}^{*}\right)}{\Psi\left(x_{O}^{\text{o}}\right)}\right]$, note that

$$\frac{\partial y}{\partial m}=\frac{4a(1+m)\mu_{R_O}{}^{2}}{\left(4a\left[(1+m)\mu_{R_O}-c\right]\right)^{2}}\left[(1+m)\mu_{R_O}-2c\right]\geq 0 \Leftrightarrow \frac{\mu_{R_O}}{c}\geq\frac{2}{1+m}$$

$$\frac{\partial yz}{\partial m}=\frac{\partial}{\partial m}\left(\frac{(1+2m)\mu_{R_O}{}^{2}}{4a\left[(1+m)\mu_{R_O}-c\right]}\right)=\left(\frac{4a\mu_{R_O}{}^{2}}{\left(4a\left[(1+m)\mu_{R_O}-c\right]\right)^{2}}\right)\left(\mu_{R_O}-2c\right)\geq 0 \Leftrightarrow \frac{\mu_{R_O}}{c}\geq 2$$

$$\frac{\partial yz}{\partial y}=\frac{\partial yz/\partial m}{\partial y/\partial m}=\frac{1}{1+m}\left(\frac{\mu_{R_O}-2c}{(1+m)\mu_{R_O}-2c}\right)<0 \;\Leftrightarrow\; \frac{\mu_{R_O}}{c}\in\left(\frac{2}{1+m},2\right)$$

$$\frac{\partial}{\partial m}\left[\frac{\Psi\left(x_{B/I}^{*}\right)}{\Psi\left(x_{O}^{\text{o}}\right)}\right]=\frac{1}{1+yz}\frac{\partial y}{\partial m}-\frac{1+y}{(1+yz)^{2}}\frac{\partial yz}{\partial m}=\left(\frac{1}{1+y}\right)\left(\frac{\Psi\left(x_{B/I}^{*}\right)}{\Psi\left(x_{O}^{\text{o}}\right)}\right)\left[1-\left(\frac{\Psi\left(x_{B/I}^{*}\right)}{\Psi\left(x_{O}^{\text{o}}\right)}\right)\frac{\partial yz}{\partial y}\right]\frac{\partial y}{\partial m}.$$

Suppose that $\frac{\mu_{R_O}}{c}\geq 2$. Note that

$$\frac{\Psi\left(x_{B/I}^{*}\right)}{\Psi\left(x_{O}^{\text{o}}\right)}=\left(\frac{1+y}{1/z+y}\right)\frac{1}{z}<\frac{1}{z} \qquad \text{(due to } z<1\text{)}$$

$$=1+\frac{m^{2}}{1+2m}\leq 1+m$$

$$\frac{\partial yz}{\partial y}=\frac{1}{1+m}\left(\frac{\mu_{R_O}-2c}{(1+m)\mu_{R_O}-2c}\right)\leq\frac{1}{1+m}$$

and thus

$$\left(\frac{\Psi\left(x_{B/I}^{*}\right)}{\Psi\left(x_{O}^{\text{o}}\right)}\right)\frac{\partial yz}{\partial y}\leq 1,$$

which implies

$$\frac{\partial}{\partial m}\left[\frac{\Psi\left(x_{B/I}^{*}\right)}{\Psi\left(x_{O}^{\mathrm{o}}\right)}\right] \geq 0.$$

Now, suppose that $\frac{\mu_{R_O}}{c} \in \left[\frac{2}{1+m}, 2\right]$. Then $\frac{\partial y}{\partial m} \geq 0$ and $\frac{\partial yz}{\partial y} \leq 0$, and

$$\frac{\partial}{\partial m}\left[\frac{\Psi\left(x_{B/I}^{*}\right)}{\Psi\left(x_{O}^{\mathrm{o}}\right)}\right] \geq 0. \square$$