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Paying for Unobservable Quality: Moral Hazard and the Challenges of Maintaining Quality along the Supply Chain

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This paper investigates how the production of high-quality agricultural goods in developing countries depends on various characteristics of the supply chain. The model predicts that the price difference between high- and low-quality goods has a range of values for which high-quality goods are produced when a single agent carries out both tasks but not when the tasks are performed by separate agents. The range of price values for which this occurs decreases as quality becomes more observable or as the cost of maintaining quality along the supply chain decreases. Policy recommendations are also discussed.

Key words: agriculture, economic development, farmer, middleman, vertical integration

Introduction

The quality of agricultural goods produced in many developing countries is often low. The *World Development Report 2008*, *Agriculture for Development* (World Bank, 2007) highlighted opportunities for farmers to increase their profits by supplying rapidly growing urban and export markets, which demand higher-quality goods. The availability of better-quality food products—which are more hygienic and higher in nutritional value—could also lead to improved health outcomes for consumers. This paper investigates the relationship between the decision to produce high-quality goods and three important characteristics of the product: the degree of observability of quality, the level of intermediation in the supply chain, and the cost of effort required to maintain quality at all stages of the supply chain.

Supply chains for agricultural goods in most developed countries tend to be short. Supply chains in many developing countries, however, tend to involve many intermediaries, such as collectors, middlemen, and brokers, who perform a variety of functions. Effort often needs to be exerted in each stage of the supply chain in order to maintain the quality of the good. For example, milk needs to be refrigerated during transportation in order to keep it free from bacteria. However, a moral hazard problem exists when effort is both unobservable and translates imperfectly into high-quality production. This can make it difficult for separate actors to coordinate along this type of supply chain. In addition, assessing the true quality of the good produced may be difficult without carrying out formal testing, requiring specialized equipment that may be costly to acquire. When the quality of the product is difficult to observe, an actor in a later stage of the supply chain may find it difficult to know whether it is worthwhile to incur the cost required to maintain high quality.

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In order to incentivize the farmer to exert effort, the middleman must pay a premium for goods that appear to be of high quality. The two types of uncertainty regarding the quality of the good (production uncertainty and an imperfect ability to observe true quality) both increase this premium. This effect, combined with the cost that the middleman must himself pay in order to maintain quality, may mean that producing high-quality goods in this market is not profitable. If a single agent carries out both tasks, however, then no added premium is required to overcome the moral hazard problem and high-quality goods are therefore more likely to be produced.

While vertical integration may be the optimal long-run way to overcome these problems in developing country markets, this may not be possible in the short term. It is important, therefore, to understand how severe this problem can be and the main factors that can exacerbate it. This paper demonstrates how the price differential required to incentivize high-quality production depends on the degree of observability of quality characteristics and the costs involved in producing and maintaining quality at each stage of the supply chain. It compares the outcomes in the two-agent case, in which both agents must exert effort to produce and preserve quality, with the case in which a single agent performs both tasks. The results show that a range of values may exist for the price differential between high- and low-quality goods for which the high-quality good is not produced in the two-agent case but is produced in the single-agent case.

Background and Related Literature

The importance of vertical integration and contract farming for the production of high-quality goods has long been recognized in the literature, and it has been argued that it is one of the factors that can explain the high level of integration seen in agricultural markets in developed countries (Hennessy, 1996). A number of authors have further examined the role that the structure of the supply chain can play in the production of high-quality goods (Vetter and Karantininis, 2002; Jang and Olson, 2010; Steiner, 2012). Gale and Hu (2012) and Wang, Wang, and Delgado (2014) discuss how the demand for higher-quality agricultural goods in China has led to increasing levels of contract farming and vertical integration in this sector.

The main channel focused on in the existing literature is the moral hazard problem of incentivizing the farmer to invest in high quality when it is imperfectly observable by the middleman. This paper contributes to the literature by highlighting a second channel through which lack of observability of quality decreases the chances of high-quality goods being produced. This is because the incentives of the middleman to exert effort to maintain quality along the supply chain are also reduced since he cannot be certain that he has received a good of high quality. The model presented in this paper is similar in spirit to Kremer's (1993) O-ring theory in that effort needs to be exerted at each stage in the production process in order to maintain quality. The model presented here does not allow for heterogeneity in levels of skill, however. Instead, it investigates how the degree of observability of quality affects the decision of agents later in the chain about whether to exert effort.

Many authors have highlighted the challenges involved in producing high-quality agricultural goods in developing countries. Robinson and Kolavalli (2010) describe the problems involved in maintaining quality in tomato markets in Ghana. They state that sales are based on quantity rather than quality, which can be difficult to assess as farmers often put poor-quality tomatoes on the bottom of the crate and better-quality tomatoes on the top. Middlemen exacerbate this problem by stacking crates on top of each other, further reducing the quality of tomatoes at the bottom of the crate. Fafchamps and Gabre-Madhin (2006) discuss the problem of assessing quality in agricultural markets in Benin. They report that inspecting quality is challenging and time consuming and traders do not want to delegate this task to others. This increases their costs and limits their ability to expand their operations.

Much of the existing literature related to quality focuses on the use of reputation to incentivize firms to produce goods of high quality. These papers describe models where consumers cannot immediately observe the quality of the good that they purchase; however, once they consume the good, they learn the quality and can punish firms that produce goods of lower quality than stated by refusing to buy from them in the future. In this case, firms receive a price premium for producing high-quality goods (Shapiro, 1983; Allen, 1984; Riordan, 1986; Gale and Rosenthal, 1994; Carriquiry and Babcock, 2017). Dana Jr. and Fong (2011) present a model that predicts that concern about loss of reputation can lead firms to produce higher-quality goods in oligopolistic markets but not monopolistic or competitive markets, while Kranton (2003) argues that competition can eliminate the price premium for reputation needed to induce production of high-quality goods.

It may be harder for reputation to sustain a high-quality equilibrium in developing countries, however, because of the high rate of seller turnover, high idiosyncratic cost fluctuations, and low entry costs (Esfahani, 1991). Fafchamps, Vargas-Hill, and Minten (2007) also suggest that reputation and repeated interaction cannot overcome the problem of poor quality in developing countries because producers are so far removed from consumers because of the large number of actors in the supply chain. They investigate the extent to which information about crop attributes is conveyed along the supply chain by examining evidence from supply chains for nonstaple food crops in India. They find that while price premiums exist for observable product characteristics, no information is circulated about unobservable characteristics. As a result, growers have no incentive to invest in unobservable quality characteristics. Because the reputation mechanism is not likely to be very strong in many developing countries, the model presented in this paper abstracts away from this aspect and focuses instead on a situation in which repeated purchases cannot act as an incentive for producing high-quality goods. It demonstrates how, even in the absence of reputational concerns, reducing the number of actors in the supply chain could lead to increased production of higher-quality goods.

The model presented in this paper highlights the challenges involved in producing high-quality products when supply chains have the following characteristics: (i) production uncertainty, (ii) imperfectly observable quality, (iii) multiple actors involved in the supply chain, and (iv) costly effort required at each stage of the supply chain in order to maintain quality. The supply chains for many products exhibit these characteristics. Notable examples are dairy and cocoa, for which quality characteristics are imperfectly observable without specialized equipment (e.g., presence of bacteria and fat content in milk and moisture and cocoa butter content in cocoa beans, Mikkelsen (2010). The final processors of these goods may test for these characteristics and pay a higher price accordingly, but smaller actors along the chain may have to rely on sight and smell, which provide imperfect measures of quality. These goods also require effort to be exerted to maintain quality along the supply chain through correct storage and transportation methods and avoiding mixing of goods of different quality grades (Badcock, Matlick, and Bako Baon, 2007). Rota and Sperandini (2010) report that transportation and handling costs make up the largest portion of marketing costs of fresh milk. Adulteration of milk along the chain is very common. Much of the adulteration is attributed to intermediaries in the chain, who try to keep the milk cool during transport by adding ice or who add washing powder and maize flour to enhance volume and whiteness (Zia, Mahmood, and Ali, 2011). Likewise, high-quality cocoa beans must be stored with care in order to preserve quality. Sacks must be secure and tight to protect from insect infestation. They also need to be kept dry and protected from high temperatures (Mikkelsen, 2010).

For both milk and cocoa, we tend to see high-quality goods being produced only when supply chains are relatively short. In developed countries, most milk is produced through co-operatives that deliver the milk directly to a processor. Farmers who do not sell their milk through co-operatives sell directly to processors themselves. The milk that is produced is rigorously tested and of high quality (Smith and Thanassoulis, 2008; DairyCo, 2011). In a number of developing country settings, the situation can be quite different. The supply chain for milk often involves many actors and is plagued by problems of low quality. The vast majority of milk that is sold is raw, unprocessed milk which must be boiled before use and is often adulterated with water (Faye and Loiseau, 2002; SNV Netherlands Development Organisation, 2008; TechnoServe Rwanda, 2008). This is not to suggest that no high-quality milk is produced in these countries. In general, however, the value chain for high-quality milk is much shorter and looks more like the supply chains for dairy seen in developed countries. In Pakistan, for example, a number of formal processors produce processed, fresh milk. They usually buy milk directly from farmers rather than through middlemen and they provide the transport themselves using refrigerated tanks (Zia, Mahmood, and Ali, 2011).

Similarly, long supply chains for cocoa tend to result in only low-quality cocoa production. Cocoa beans in Indonesia, for example, are generally purchased on the basis of quantity rather than quality. Collectors do not differentiate on the basis of quality in terms of the price that they pay the farmer. In addition, they mix beans of different quality with each other and sometimes also with waste material in an effort to increase volume (Panlibuton and Lusby, 2006). In contrast, the supply chain in Ghana is much shorter and the cocoa that is produced is of much higher quality. The cocoa industry in Ghana is strictly regulated by the Cocoa Marketing Board, Cocobod. Farmers either sell directly to licensed buying companies (LBCs) or to farmers' associations, both of which sell directly to Cocobod (Mohammed, Asamoah, and Asiedu-Appiah, 2012; Williams, 2009).

On the other hand, longer supply chains may produce higher quality goods when quality characteristics are easily observable, such as for rice and chilies. Farmers in South Sulawesi, Eastern Indonesia, produce two main types of chili: large chili and small chili. Large chili is considered to be of higher quality and sells for a higher price, but its production is also more costly. Different inputs and techniques are used, including the use of certified seed (White et al., 2007). Collectors and wholesalers must also exert some effort—including sorting, grading and packaging—to sell high-quality chili to supermarkets. Even though the supply chain for large chili is quite long, there is a market for it. Large chili is widely produced, and farmers receive a higher price for producing it (White et al., 2007). Another product with easily observable quality characteristics is rice, where the length and broken level of the grain indicate quality (Hai, 2003). In Vietnam and Thailand, both large rice-producing countries, many actors are involved in the supply chain for rice: producers, assemblers, middlemen/brokers, wholesalers, millers/polishers, and retailers. Most rice traders in Vietnam differentiate rice into two types: higher-quality long and medium/short. Long-grain rice is widely grown and the growers receive a higher price (Agrifood Consulting International, 2005). In the case of both chili and rice, quality characteristics are easily observable, and so high-quality goods are produced even where there are many agents participating in the supply chain, each exerting effort to maintain quality.

Model

The model focuses on the key characteristics of agricultural markets in developing countries and demonstrates the impact of low observability of quality characteristics on incentives to produce high-quality goods, both in a two-agent case where both agents must exert effort to produce and preserve quality and in the case where both tasks are performed by a single agent.

Economic Environment

I describe the supply chain of a good that involves two stages of production. This paper uses the example of a farmer and middleman, but the model could be applied to other situations. The good can have two possible quality levels: high or low, $Q \in \{H, L\}$. The final market price for a high-quality good is p^H and the price for a low-quality good is p^L. The quality of the good is perfectly observable to the final purchaser (e.g., a large processing company that has the technology to test for quality) but not at the intermediate production stage. A higher level of effort is required at both stages of the production process to produce a good of high quality. This effort is costly. The timing of the production process is as follows:

(i) The decision is made about whether to exert high effort in the first stage of production. The cost of this effort is c^F. If high effort is exerted, the probability that the good produced will be of high quality is γ. If low effort is exerted, the good will be of low quality with certainty.

(ii) A signal, $s \in \{H, L\}$, regarding the quality of the good is received, where $s = Q$ with probability $\rho \in (0.5, 1]$. This parameter gives us a measure of the observability of quality. If ρ is close to 0.5, then it is very difficult to observe quality. If $\rho = 1$, then quality is perfectly observable.

(iii) The decision is made about whether to exert high effort in the second stage of production in order to maintain the good's quality. The cost of this effort is c^M. If effort is exerted at this stage, the quality of the good will be preserved with certainty. If effort is not exerted, the quality of the good will be low.

(iv) The quality of the good is perfectly observed in the final stage. p^H will be received for the good if $Q = H$, and p^L will be received if $Q = L$.

Separate Agents

Suppose there are two agents, a farmer and a middleman, both of whom are assumed to be risk neutral. The farmer carries out the first stage of production and the middleman carries out the second stage. I assume that the middleman is the residual claimant of the profit from production so I use a principal–agent framework in which the principal also must exert effort at some stage in the production process. Before production decisions are made, the middleman must choose the optimal contract to offer the farmer. The middleman cannot observe the farmer's effort level and cannot perfectly observe the quality of the good. His payment to the farmer can therefore only be based on the signal of quality that he receives. The middleman must choose h, the payment made to the farmer when $s = H$, and l, the payment made to the farmer when $s = L$. In order for the middleman to decide on the optimal contract to offer, he must first understand how the farmer will react. Therefore, we begin by looking at the farmer's decision problem.

Farmer's Problem

If the farmer exerts high effort, his expected payoff is

$$\gamma[\rho h + (1-\rho)l] + (1-\gamma)[(1-\rho)h + \rho l] - c^F. \tag{1}$$

If he does not exert high effort, his expected payoff is

$$(1-\rho)h + \rho l. \tag{2}$$

The farmer will therefore exert effort if the following incentive compatibility constraint is satisfied:

$$h - l \geq \frac{c^F}{(2\rho - 1)\gamma}. \tag{3}$$

I assume that a limited liability constraint applies so that $l \geq 0$. This assumption is important but not unreasonable. It means that we assume that the middleman cannot force the farmer to pay him if he receives a low signal. It is reasonable to assume that the worst that the middleman could do to the farmer would be to refuse to purchase the good. The farmer must also be willing to participate in the contract. The value of the farmer's outside option is normalized to 0. The following participation constraint must be satisfied in order for the farmer to accept the contract:[1]

$$\gamma[\rho h + (1-\rho)l] + (1-\gamma)[(1-\rho)h + \rho l] - c^F \geq 0. \tag{4}$$

[1] If the values of h and l are such that the incentive compatibility constraint is satisfied, then the participation constraint is also satisfied.

Given the above constraints, from the point of view of the middleman, the optimal h and l that will induce the farmer to exert effort are[2]

$$h^* = \frac{c^F}{(2\rho - 1)\gamma}; \qquad l^* = 0. \tag{5}$$

If the middleman chooses not to induce effort, then he will simply offer l^* to the farmer regardless of the signal received. The farmer then exerts no effort and receives the value of his outside option, which is 0.

Middleman's Problem

The middleman's profit depends on the realized quality of the good. If the good is of high quality, he receives p^H; if it is of low quality, he receives p^L. The middleman has two decisions to make. He must first decide whether to exert effort himself in the second stage (and incur cost c^M) and he must then decide whether to offer the farmer the contract that induces the farmer to exert effort in the first stage. His decision about whether to induce the farmer to exert effort depends on his own willingness to exert effort in the second stage.

Second Stage

The middleman only exerts effort in the second stage of production if he believes that effort was exerted in the first stage. If he has offered $h \geq h^*$ in the first stage, then he will believe that the farmer exerted effort in the first stage with probability 1. If he has offered $h < h^*$ in the first stage, then he will believe that the farmer exerted effort in the first stage with probability 0.

If the middleman believes that no effort was exerted in the first stage, then he will believe that the good is of low quality with probability 1, regardless of the signal received, and he will therefore also exert no effort himself. If he believes that effort has been exerted in the first stage, then his prior belief that the good is of high quality equals γ. In this case, after he receives the signal regarding the quality of the good, he updates his beliefs as follows:

$$\mu^H = \text{Prob}(Q = H \mid s = H) = \frac{\gamma\rho}{\gamma\rho + (1-\gamma)(1-\rho)}; \qquad \mu^L = \text{Prob}(Q = H \mid s = L) = \frac{\gamma(1-\rho)}{\gamma(1-\rho) + (1-\gamma)\rho}. \tag{6}$$

The middleman then decides whether to exert effort himself. Once he is in the second stage, the costs from the first stage are sunk, so his decision only depends on his belief about the quality of the good, the cost of effort required to preserve the quality of the good, and the difference in price between a high-quality and a low-quality good. Let $\tilde{p} = p^H - p^L$.

If the following condition holds, the middleman will exert effort in the second stage when he receives a signal that the good is of high quality:[3]

$$\tilde{p} \geq c^M \left(\frac{\gamma\rho + (1-\gamma)(1-\rho)}{\gamma\rho} \right). \quad \text{(Constraint 1)} \tag{7}$$

[2] For these values of h and l, the farmer's incentive compatibility constraint binds. As he is indifferent between exerting effort and no effort at this point, we focus on the strategy where he chooses to exert effort, as that is the only case in which an equilibrium exists.

[3] This expression is derived from the following inequality: $\mu^H p^H + (1-\mu^H)p^L - c^M \geq p^L$, which means that his expected return to exerting effort, conditional on receiving a signal that the good is of high quality, is greater than his expected return from not exerting effort.

He will exert effort in the final stage when he receives a signal that the good is of low quality if the following condition holds:[4]

$$\tilde{p} \geq c^M \left(\frac{\gamma(1-\rho) + (1-\gamma)\rho}{\gamma(1-\rho)} \right). \quad \text{(Constraint 2)} \tag{8}$$

The second condition is stronger so if the middleman is willing to exert effort when he receives a low signal, he is also willing to exert effort when he receives a high signal.

First Stage

The middleman knows the choices that he will make in the second stage if effort is exerted by the farmer. Therefore, he must use this information to decide whether to induce the farmer to exert high effort in the first stage. The following two lemmas provide details of the parameter values for which the middleman is willing to induce high effort in the first stage:

LEMMA 1. *If* $c^M(\frac{\gamma(1-\rho)+(1-\gamma)\rho}{\gamma(1-\rho)}) \geq \tilde{p} \geq c^M(\frac{\gamma\rho+(1-\gamma)(1-\rho)}{\gamma\rho})$, *the middleman will induce the farmer to exert high effort if the following condition holds:*

$$\tilde{p} \geq \frac{\gamma\rho + (1-\gamma)(1-\rho)}{\gamma\rho} \left(\frac{c^F}{(2\rho-1)\gamma} + c^M \right). \quad \text{(Constraint 3)} \tag{9}$$

Otherwise, only low-quality goods will be produced.[5]

For these parameter values, the middleman is only willing to exert effort in the final stage if he receives a signal that the good is of high quality. The probability of successfully producing a good of high quality is therefore $\gamma\rho$. He is only willing to induce the farmer to exert high effort if his expected gain is greater than the expected cost that he has to pay, which is true if $\tilde{p}$ satisfies Constraint 3. In this case, the middleman only pays h and c^M when a high signal is received.

LEMMA 2. *If* $\tilde{p} \geq c^M(\frac{\gamma(1-\rho)+(1-\gamma)\rho}{\gamma(1-\rho)})$, *the middleman will induce the farmer to exert high effort if the following condition holds:*

$$\tilde{p} \geq \frac{\gamma\rho + (1-\gamma)(1-\rho)}{\gamma} \left(\frac{c^F}{(2\rho-1)\gamma} \right) + \frac{c^M}{\gamma}. \quad \text{(Constraint 4)} \tag{10}$$

Otherwise, only low-quality goods will be produced.[6]

In this case, $\tilde{p}$ is large enough relative to c^M that the middleman is always willing to exert effort in the second stage if he believes effort has been exerted in the first stage, regardless of the value of the signal that he receives (i.e., Constraint 2 is satisfied). Given this, the probability of producing a good of high quality is now γ. In this case, however, the middleman always pays c^M. He therefore considers this cost when deciding whether to induce effort in the first stage. As long as $\tilde{p}$ satisfies Constraint 4, it is profitable for the middleman to induce the farmer to exert effort in the first stage.

The middleman's decision regarding the level of effort to exert therefore depends on the relative parameter values. The possible effort levels that the middleman could choose are as follows:[7]

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[4] This expression is derived from the following inequality: $\mu^L p^H + (1-\mu^L)p^L - c^M \geq p^L$, which means that his expected return to exerting effort, conditional on receiving a signal that the good is of low quality, is greater than his expected return from not exerting effort.

[5] See the online supplement (www.jareonline.org) for proof.

[6] See the online supplement for proof.

[7] It is also possible that the middleman could play a mixed strategy over his own choice of effort levels if the parameter values are such that either Constraint 1 or Constraint 2 hold with equality. This could only be the case for very particular parameter values, however, so we focus instead on the case in which he chooses to exert effort when indifferent.

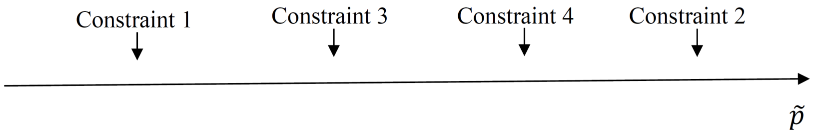

Figure 1. Ordering of Constraints in the Two-Agent Case for the Parameter Values Given in Proposition 1(a)

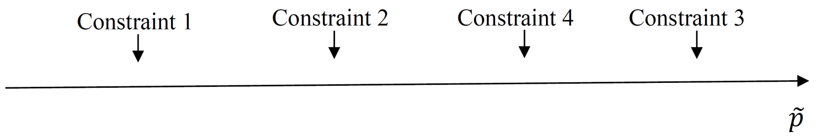

Figure 2. Ordering of Constraints in the Two-Agent Case for the Parameter Values Given in Proposition 1(b)

(i) Full effort: The middleman induces the farmer to exert high effort and always exerts effort himself. In this situation, the probability of high-quality goods being produced is equal to γ.

(ii) Partial effort: The middleman induces the farmer to exert high effort and exerts effort himself when he receives a high signal. In this situation, the probability of high-quality goods being produced is equal to $\gamma\rho$.

(iii) No effort: The middleman does not induce the farmer to exert high effort and the farmer always produces low-quality goods. In this situation, the probability of high-quality goods being produced is equal to 0.

This leads us to the following proposition, which outlines the various levels of effort exerted in equilibrium for the full range of possible parameter values: In almost all cases, there is a unique subgame-perfect equilibrium in this game. If the parameter values are such that either Condition 3 or Condition 4 holds with equality, then mixed-strategy equilibria will also exist. However, as these are very particular cases, this paper does not discuss these equilibria.

PROPOSITION 1(a). *Suppose* $\frac{c^M}{c^F} \geq \frac{\gamma\rho+(1-\gamma)(1-\rho)}{(2\rho-1)\gamma}\left(\frac{1-\rho}{(2\rho-1)(1-\gamma)}\right)$. *If* $\tilde{p}$ *is such that Constraint 3 is not satisfied, no effort will be exerted. If* $\tilde{p}$ *is such that Constraint 3 is satisfied but Constraint 2 is not satisfied, then partial effort will be exerted. If Constraint 2 is satisfied, then full effort will be exerted.*

PROPOSITION 1(b). *Suppose* $\frac{c^M}{c^F} < \frac{\gamma\rho+(1-\gamma)(1-\rho)}{(2\rho-1)\gamma}\left(\frac{1-\rho}{(2\rho-1)(1-\gamma)}\right)$. *If Constraint 4 is not satisfied, no effort will be exerted. If Constraint 4 is satisfied, then full effort will be exerted.*[8]

For the parameter values in Proposition 1(a), the conditions on $\tilde{p}$ for each constraint to be met relate to each other, as shown in Figure 1. If $\frac{c^M}{c^F} \geq \frac{\gamma\rho+(1-\gamma)(1-\rho)}{(2\rho-1)\gamma}\left(\frac{1-\rho}{(2\rho-1)(1-\gamma)}\right)$, then c^M is relatively more important than c^F. This means that the middleman is willing to induce the farmer to exert high effort at values of $\tilde{p}$ that are lower than the value at which he himself would be willing to exert full effort. When $\tilde{p}$ is low, no effort is exerted. As $\tilde{p}$ increases, we reach the following situation:

$$c^M\left(\frac{\gamma(1-\rho)+(1-\gamma)\rho}{\gamma(1-\rho)}\right) \geq \tilde{p} \geq \frac{\gamma\rho+(1-\gamma)(1-\rho)}{\gamma\rho}\left(\frac{c^F}{(2\rho-1)\gamma}+c_M\right). \tag{11}$$

At this point, Constraint 3 (and therefore also Constraint 1) is satisfied but Constraint 2 is not, meaning that the middleman is willing to exert partial effort. Once $\tilde{p}$ is high enough that Constraint 2 is satisfied, then full effort is exerted.

[8] See the online supplement for proof.

For the parameter values in Proposition 1(b), the conditions on $\tilde{p}$ for each constraint to be met relate to each other, as shown in Figure 2. If $\frac{c^M}{c^F} < \frac{\gamma\rho+(1-\gamma)(1-\rho)}{(2\rho-1)\gamma}(\frac{1-\rho}{(2\rho-1)(1-\gamma)})$, then c^F is relatively more important than c^M. This means that Constraints 2 and 4 are satisfied at lower levels of $\tilde{p}$ than Constraint 3 (which is the relevant constraint for partial effort). The middleman is always willing to incur c^M in the final stage (conditional on effort being exerted in the first stage) at values of $\tilde{p}$ that are lower than the value at which he is willing to pay enough to induce the farmer to exert high effort. Therefore, partial effort is never exerted in this case. As long as $\tilde{p}$ is low enough that Constraint 4 is not satisfied, then no effort is exerted. Once $\tilde{p}$ increases to the point where Constraint 4 is satisfied, then Constraint 2 is also satisfied, and therefore full effort is exerted.

Single-Agent Case

Now, suppose there is just one agent who carries out both tasks. As in the case with two agents, his decision about whether to exert effort in the first stage depends on his willingness to exert effort in the second stage.

Second Stage

The agent knows whether he exerted effort in the first stage. If he did not exert effort in the first stage, then he does not exert effort in the second stage as he knows that the good is of low quality. If he exerted effort in the first stage, then his decision to exert effort in the second stage depends on his beliefs regarding the quality of the good. These beliefs are formed based on the signal that he receives in the same way that the beliefs were formed by the middleman in the case with two agents. If Constraint 1 is satisfied but Constraint 2 is not, then he will exert effort in the second stage only when he receives a signal that the good is of high quality. If Constraint 2 is satisfied, then he will exert effort regardless of the signal received.

First Stage

The conditions that need to be satisfied in order for effort to be exerted in the first stage are different from in the case with two agents, as there is no longer a moral hazard problem. The following two lemmas present the parameter values for which the agent is willing to exert effort in the first stage, in the single-agent case:

LEMMA 3. *If $c^M(\frac{\gamma(1-\rho)+(1-\gamma)\rho}{\gamma(1-\rho)}) \geq \tilde{p} \geq c^M(\frac{\gamma\rho+(1-\gamma)(1-\rho)}{\gamma\rho})$, the agent will exert effort in the first stage if the following condition holds:*

$$\tilde{p} \geq \frac{c^F}{\gamma\rho} + \left(\frac{\gamma\rho + (1-\gamma)(1-\rho)}{\gamma\rho}\right)c^M. \quad \text{(Constraint 5)} \tag{12}$$

Otherwise, only low-quality goods will be produced.[9]

As in the case with two agents, for this value of $\tilde{p}$, the agent is only willing to exert effort in the second stage if he receives a high signal. The probability of success is therefore $\gamma\rho$. The cost that he has to pay for effort to be exerted in the first stage is now smaller, however, as he does not have to pay a premium to overcome the moral hazard problem. As long as Constraint 5 is satisfied, then his expected profit from exerting effort in the first stage is higher than not exerting effort.

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[9] See the online supplement for proof.

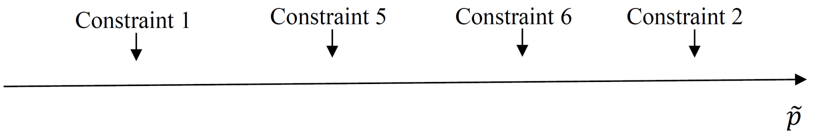

Figure 3. Ordering of Constraints in the Single-Agent Case for the Parameter Values Given in Proposition 2(a)

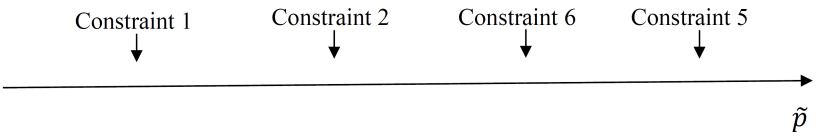

Figure 4. Ordering of Constraints in the Single-Agent Case for the Parameter Values Given in Proposition 2(b)

LEMMA 4. *If $\tilde{p} \geq c^M(\frac{\gamma(1-\rho)+(1-\gamma)\rho}{\gamma(1-\rho)})$, the agent will exert effort in the first stage if the following condition holds:*

(13) $$\tilde{p} \geq \frac{c^F + c^M}{\gamma} \quad \text{(Constraint 6)}.$$

Otherwise, only low-quality goods will be produced.[10]

In this situation, the agent is always willing to exert effort in the second stage if effort is exerted in the first stage. Therefore, it is as if there is just one task to be carried out and the cost is $c^F + c^M$. The probability of success is γ. Therefore, as long as Constraint 6 is satisfied, it is profitable to exert effort in the first stage.

The agent again must choose between three possible effort levels: full, partial, and no effort. The following proposition outlines the various levels of effort which are exerted in equilibrium for the full range of possible parameter values. It is analogous to Proposition 1 for the two-agent case, although the relevant cut-off parameter values are different.

PROPOSITION 2(a). *Suppose $\frac{c^M}{c^F} \geq \frac{1-\rho}{(2\rho-1)(1-\gamma)}$. If $\tilde{p}$ is such that Constraint 5 is not satisfied, no effort will be exerted. If $\tilde{p}$ is such that Constraint 5 is satisfied but Constraint 2 is not satisfied, then partial effort will be exerted. If Constraint 2 is satisfied, then full effort will be exerted.*

PROPOSITION 2(b). *Suppose $\frac{c^M}{c^F} < \frac{1-\rho}{(2\rho-1)(1-\gamma)}$. If $\tilde{p}$ is such that Constraint 6 is not satisfied, then no effort will be exerted. If $\tilde{p}$ is such that Constraint 6 is satisfied, then full effort will be exerted.*[11]

This situation in Proposition 2(a) is comparable to that in Proposition 1(a). For these parameter values, the conditions on $\tilde{p}$ for each constraint to be met relate to each other, as shown in Figure 3. When $\tilde{p}$ is low, no effort is exerted. As $\tilde{p}$ increases, we reach the following situation:

(14) $$c^M\left(\frac{\gamma(1-\rho)+(1-\gamma)\rho}{\gamma(1-\rho)}\right) \geq \tilde{p} \geq \frac{c^F}{\gamma\rho} + \left(\frac{\gamma\rho+(1-\gamma)(1-\rho)}{\gamma\rho}\right)c^M.$$

At this point Constraint 5 is satisfied (and therefore also Constraint 1), but Constraint 2 is not, meaning that the middleman is willing to exert partial effort. Once $\tilde{p}$ is high enough that Constraint 2 is satisfied, then full effort is exerted.

[10] See the online supplement for proof.
[11] See the online supplement for proof.

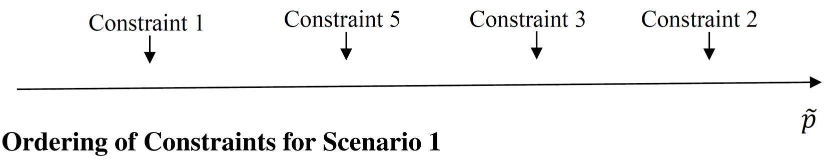

Figure 5. Ordering of Constraints for Scenario 1

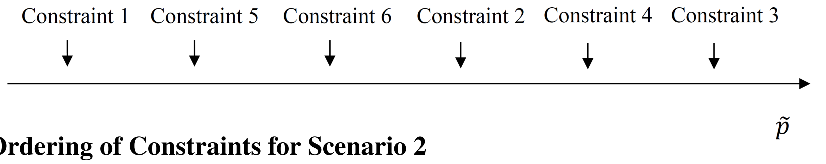

Figure 6. Ordering of Constraints for Scenario 2

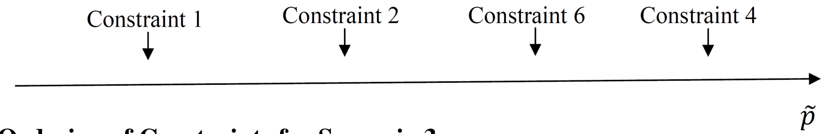

Figure 7. Ordering of Constraints for Scenario 3

In the situation in Proposition 1(b), c^F is relatively more important and so either no effort is exerted or full effort is exerted, as Constraint 5 is the most difficult constraint to satisfy. This is comparable to Proposition 1(b) in the two-agent case. For these parameter values, the conditions on $\tilde{p}$ for each constraint to be met relate to each other, as shown in Figure 4. If Constraint 6 is not satisfied, then no effort is exerted. Once $\tilde{p}$ is large enough that Constraint 6 is satisfied then full effort is exerted.

While the conditions outlined in this proposition seem very similar to those presented in Proposition 1, there are some important differences. In particular, the required condition on the parameter values to be in situation (a) versus situation (b) is different. As $\frac{\gamma\rho+(1-\gamma)(1-\rho)}{(2\rho-1)\gamma}\left(\frac{1-\rho}{(2\rho-1)(1-\gamma)}\right) > \frac{1-\rho}{(2\rho-1)(1-\gamma)^2}$, situation (a) applies for a lower value of c^M/c^F in the single-agent case than in the two-agent case. This is because the actual cost of making sure that effort is exerted in the first stage is greater in the case with two agents. Within each situation, the conditions to move to higher levels of effort hold for different values of $\tilde{p}$ in the single-agent case than in the two-agent case, as discussed in the next section.

Two-Agent Case versus Single-Agent Case

We can now compare the effort levels exerted in the single- versus the two-agent case for a given price differential between high- and low-quality goods.

PROPOSITION 3. *For all possible parameter values, higher values of $\tilde{p}$ will be required in order to induce higher effort levels in the two-agent case than in the single-agent case. High-quality goods will therefore be more likely to be produced at lower levels of $\tilde{p}$ in the single-agent case.*[12]

In order to demonstrate that this proposition is true for all possible parameter values, we must separately examine three possible scenarios for the relative values of c^M and c^F, which collectively cover all possible values. Scenario 1 applies for the following parameter values:

$$(15) \qquad \frac{c^M}{c^F} \geq \frac{\gamma\rho+(1-\gamma)(1-\rho)}{(2\rho-1)\gamma}\left(\frac{1-\rho}{(2\rho-1)(1-\gamma)}\right) > \frac{1-\rho}{(2\rho-1)(1-\gamma)}.$$

[12] See the online supplement for proof.

For these parameter values, the conditions on $\tilde{p}$ for each relevant constraint to be met relate to each other as shown in Figure 5 (Constraints 4 and 6 are omitted as they are not relevant in this case, since they are easier to satisfy than Constraint 2).

In Scenario 1, the cost of effort in the second stage is high relative to the first stage, which means that only partial effort is exerted for some values of $\tilde{p}$. For low values of $\tilde{p}$, no effort is exerted, regardless of the number of agents involved in production. As $\tilde{p}$ increases, we first hit the partial effort constraint for the single-agent case (Constraint 5). If $\tilde{p}$ is such that Constraint 5 is satisfied but Constraint 3 is not, then high-quality goods are produced in the single-agent case but not in the two-agent case. Once $\tilde{p}$ becomes greater than $c^M(\frac{\gamma(1-\rho)+(1-\gamma)\rho}{\gamma(1-\rho)})$, Constraint 2 is satisfied and therefore full effort is exerted regardless of the structure of the supply chain.

Scenario 2 applies for the following parameter values:

$$\frac{\gamma\rho+(1-\gamma)(1-\rho)}{(2\rho-1)\gamma}\left(\frac{1-\rho}{(2\rho-1)(1-\gamma)}\right)>\frac{c^M}{c^F}\geq\frac{1-\rho}{(2\rho-1)(1-\gamma)}. \tag{16}$$

For these parameter values, the conditions on $\tilde{p}$ for each relevant constraint to be met relate to each other, as shown in Figure 6. For these parameter values, the agent is willing to exert partial effort for some values of the price in the single-agent case but never in the two-agent case. If

$$c^M\left(\frac{\gamma(1-\rho)+(1-\gamma)\rho}{\gamma(1-\rho)}\right)>\tilde{p}\geq\frac{c^F}{\gamma\rho}+\left(\frac{\gamma\rho+(1-\gamma)(1-\rho)}{\gamma\rho}\right)c^M \tag{17}$$

is true, then Constraint 5 is satisfied but Constraint 2 is not and therefore partial effort is exerted in the single-agent case but no effort is exerted in the two-agent case. As $\tilde{p}$ increases, Constraint 2 is satisfied. At that point, Constraint 6 is already satisfied but Constraint 4 is not; therefore full effort is exerted in the single-agent case but still no effort is exerted in the two-agent case. Once $\tilde{p}$ becomes large enough that Constraint 4 is satisfied, then full effort is also exerted in the two-agent case.

Scenario 3 applies for the following parameter values:

$$\frac{\gamma\rho+(1-\gamma)(1-\rho)}{(2\rho-1)\gamma}\left(\frac{1-\rho}{(2\rho-1)(1-\gamma)}\right)>\frac{1-\rho}{(2\rho-1)(1-\gamma)}>\frac{c^M}{c^F}. \tag{18}$$

For these parameter values, the conditions on $\tilde{p}$ for each relevant constraint to be met relate to each other, as shown in Figure 7 (Constraints 3 and 5 are not included as they are not relevant, since they are harder to satisfy than Constraint 4). For these parameter values, the cost in the second stage is low relative to that in the first stage, which means that partial effort is never exerted in either case. Therefore, we only need to compare the conditions for full effort to be exerted. As before, this condition is satisfied for lower values of $\tilde{p}$ in the single-agent case than in the two-agent case, as Constraint 6 is easier to satisfy than Constraint 4. If $\tilde{p}$ lies between the values required to satisfy these constraints, then high-quality goods are produced in the single-agent case but not in the two-agent case.

Comparative Statics

The results from the previous section show that there is a range of values of $\tilde{p}$ for which high-quality goods are produced in the single-agent case but not in the two-agent case. The size of this range is determined by the difference between the minimum $\tilde{p}$ required to induce any high-quality production (either full or partial effort) in each case. I refer to the width of this difference in the minimum values of $\tilde{p}$ as the "quality gap."

The relevant expression for the quality gap depends on the scenario (based on the relative values of the parameters). In Scenario 1, it is defined by the difference between the value of $\tilde{p}$ required to satisfy Constraint 3 and that required to satisfy Constraint 5 (see Figure 5), represented by

$$\frac{1-\rho}{\gamma^2\rho(2\rho-1)}c^F. \tag{19}$$

In Scenario 2, high-quality goods are still produced in the single-agent case once Constraint 5 is satisfied. For the two-agent case, however, Constraint 4 is now satisfied at lower values of $\tilde{p}$ than Constraint 3 (see Figure 6). Therefore, in this scenario, the quality gap is given by the difference between Constraints 4 and 5, represented as

$$\left[\frac{\rho(\gamma\rho + (1-\gamma)(1-\rho)) - \gamma(2\rho - 1)}{\gamma^2\rho(2\rho - 1)}\right] c^F + \frac{(2\rho - 1)(1-\gamma)}{\gamma\rho} c^M. \tag{20}$$

Finally, in Scenario 3, Constraint 6 is satisfied before Constraint 5 (see Figure 7), so the quality gap is now given by the difference between Constraints 4 and 6, represented as

$$\frac{1-\rho}{\gamma^2(2\rho - 1)} c^F. \tag{21}$$

As the cost of producing high-quality goods and the ability to observe quality improve, the production of high-quality goods will be incentivized in all cases. However, these parameters have a different impact in the two-agent case than in the single-agent case because of the way in which they affect the moral hazard problem. Changes in these parameters, therefore, influence the size of the quality gap. The following sections discuss the differential impact of each of the key parameters.

Degree of Observability, ρ

As ρ increases, the range of values of $\tilde{p}$ over which it is profitable to produce high-quality increases in both the single- and two-agent case. However, as the price that the middleman must pay to the farmer in the two-agent case is decreasing in ρ, the rate of increase in this range of values is higher in the two-agent case than in the single-agent case and therefore the quality gap becomes smaller. We can see this by examining the expressions for the quality gap in each scenario.

For a given c^M/c^F, if ρ is small we are in Scenario 3, and only full effort or no effort is exerted. As ρ increases, we eventually move to Scenario 2 and finally to Scenario 1. In each of these scenarios, the expression for the quality gap is decreasing in ρ and gets progressively smaller as we move through the scenarios (for the relevant parameter values that define the cut-off points between scenarios, the expressions for the quality gap in each scenario are equal). Finally, when $\rho = 1$, the difference disappears and there is no loss in efficiency from not having an integrated supply chain.

The Farmer's Cost, c^F

Because quality is not perfectly observable, the price paid to the farmer in the two-agent case is increasing in c^F by a factor that is greater than 1, whereas in the single-agent case it enters the agent's costs of production directly. This means that a reduction in c^F has a greater impact in the two-agent case than in the single-agent case and therefore reduces the quality gap. For a given c^M and ρ, if c^F is high, we are in Scenario 3. As c^F falls we move from Scenario 3 to Scenario 2 and eventually to Scenario 1. In each successive case, the quality gap is smaller, and within each of these scenarios it is decreasing in c^F. As c^F goes to 0, the quality gap also goes to 0.

The Middleman's Cost, c^M

As with c^F, as c^M falls, the quality gap falls. Unlike c^F and ρ, however, c^M does not influence the price that is paid to the farmer in the two-agent case. The middleman's cost is most relevant for his decision regarding his own level of effort (although also ultimately influences the decision to incentivize effort in the first stage). As such, it has the greatest impact on the quality gap through determining which of the scenarios we are in. It also influences the size of the gap in Scenario 2 as, in this scenario, partial effort is exerted in the single-agent case but not in the two-agent case.

For a given ρ and c^F, if c^M is sufficiently high we are in Scenario 1. The expression for the quality gap in this case does not depend on $c^M$and, therefore, as long as we remain in this scenario, the quality gap remains constant as c^M falls. However, eventually c^M becomes small enough that we move to Scenario 2. In this scenario, the gap is now increasing in c^M and therefore falls as c^M continues to fall. We can also say that this gap is smaller than it was in Scenario 1, since at the cut-off point, the two are equal. Finally, if c^M continues to fall, we move to Scenario 3. Once again, in this scenario the size of the gap is smaller than in the previous scenarios. It no longer depends on c^M, however, so it remains constant from now on as c^M falls.

Summary of Findings

The decision to produce high-quality goods depends on the costs of production, the degree of observability of quality, and the price difference between goods of high and low quality. If quality is not perfectly observable, it is more costly to the middleman to overcome the problem of the farmer's moral hazard. He therefore needs a larger price difference between high- and low-quality goods in order to convince him to induce effort in the farmer and exert effort himself. The lack of observability of quality increases the cost of production of high-quality goods in the first stage when the two stages are carried out by different agents but not in the single-agent case. This creates a "quality gap," as there is a range of values of the price difference between high- and low-quality goods for which high-quality goods are produced in the single-agent case but not in the two-agent case. In addition to increasing the first-stage cost of producing high-quality goods, a lower ρ also decreases the likelihood that partial effort is exerted as this only happens when the expected cost paid to the farmer is low relative to c^M. This also increases the quality gap.

Policy Implications

We have seen that the existence of multiple agents in the supply chain results in an efficiency loss if the quality of a good is not perfectly observable. The size of this efficiency loss depends on how difficult it is to accurately measure quality and on the costs of producing and maintaining this high quality along the length of the supply chain. Based on these results, policy makers have several options to try to improve efficiency.

The first approach that policy makers could take would be to encourage more vertical integration in the supply chain. For example, the government could support the formation of farmers' associations, which could perform some of the middleman's tasks (e.g., transporting goods to the processor). Alternatively, processors could be encouraged to establish operations "up country" in order to buy directly from farmers and test for quality earlier in the supply chain. Both options aim to eliminate this efficiency loss by reducing the degree of intermediation in the supply chain. However, in many situations, particularly in developing countries, this may not be possible or even desirable. Intermediaries often perform other important functions, such as providing access to inputs and credit, that are important for farmers. Their transportation costs may also be lower than farmers' since they operate at a different scale; intermediation may therefore provide other efficiency gains. It is therefore important for us to understand other ways in which policy makers could encourage the production of high-quality goods in these intermediated markets.

The ability to accurately observe product quality is a key part of this problem. If intermediaries were able to accurately and credibly measure the true quality of the good, then this would eliminate the moral hazard problem and efficiency could be achieved. Policy makers could support the development of technology for measuring quality attributes and encourage access to this technology for intermediaries. In addition, any policy that would reduce the costs of producing and maintaining high-quality goods would also provide an efficiency gain. Reducing these costs would of course generally encourage the production of high-quality goods at a lower price premium in both the single- and two-agent case but would have a greater impact in the two-agent case, thereby further reducing the efficiency loss from intermediation. Policies that reduce the costs to the producers should have the greatest impact. Extension programs that provide support to farmers or encouraging farmers to work together in co-operatives could reduce their costs of production which would in turn reduce the quality gap.

In addition, a key takeaway from the results is that attention should also be paid to the costs of maintaining quality along the entire supply chain; reductions in these costs should also reduce the size of the quality gap. Improvements in market access (e.g., improvements to roads) would help to reduce the costs to the intermediary of transporting the goods and thereby reduce the cost of maintaining the quality on the journey, which once again would cause a reduction in the quality gap.

Conclusion

This paper presented a model of a supply chain that demonstrated that the decision to produce low-quality goods can be explained by a combination of low observability of quality, high level of intermediation in the supply chain, and costly effort required to maintain quality at each stage in the supply chain. The model predicts that if the quality of the good is not perfectly observable, then a "quality gap" exists. This means that the price difference between high- and low-quality goods has a range of values for which high-quality goods are produced if the supply chain involves a single agent but not if the tasks are performed by separate agents.

It has long been understood that for many reasons it is harder to produce higher quality goods with longer supply chains. However, moving toward a shorter supply chain may not be easily achieved or even desirable in a number of developing country settings. It is still important, however, to understand what can be done to incentivize the production of higher-quality goods in this case. The model presented in this paper predicts that the size of the quality gap is decreasing in the degree of observability of quality and increasing in the cost to the farmer of producing a high-quality good and the cost to the middleman of preserving the quality of the good. This means that, from a policy perspective, it is important to pay attention not just to the farmer's costs of investing in high quality but also the costs involved in all stages of the supply chain in order to maintain quality until the good reaches the final consumer. If these costs could be reduced, it is possible that the production of higher quality goods could be incentivized, even in a longer supply chain. Technologies that allow for easier testing of quality at different stages in the supply chain could also help to overcome the moral hazard problem.

The analysis in this paper has taken the degree of integration of the supply chain as exogenous in order to better understand one side of the problem. In reality, the decision of whether to vertically integrate may be endogenous. Incorporating this into the model could be an important avenue for future research. This decision to integrate involves a number of different considerations, and it may not always be optimal for a single agent to perform all tasks. However, in any situation where the supply chain is not fully integrated, problems of producing and maintaining high quality will persist, and attention should be paid in these cases to the factors that can exacerbate this problem.

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Online Supplement: Paying for Unobservable Quality: Moral Hazard and the Challenges of Maintaining Quality along the Supply Chain

Tara Mitchell

Proof of Lemma 1. For these parameter values, $\tilde{p}$ is such that Constraint (1) is satisfied but Constraint (2) is not satisfied. This means that if the middleman has induced effort by the farmer in the first stage, he will exert effort himself in the second stage only if a signal of high quality has been received. His expected payoff from inducing the farmer to exert effort in the first stage will therefore equal:

$$\gamma\left[\rho\left(p^H - c^M - \frac{c^F}{(2\rho-1)\gamma}\right) + (1-\rho)p^L\right] + (1-\gamma)\left[p^L - (1-\rho)\left(c^M + \frac{c^F}{(2\rho-1)\gamma}\right)\right]$$

If he does not induce effort in the farmer, then only low-quality goods will be produced. In this case he will pay the farmer the value of his outside option (normalized to zero) regardless of the signal and will never exert effort himself in the second stage. His expected profit in this case will equal p^L. He will therefore choose to induce effort in the first stage when the above expression is at least as large as p^L, which will be true when

$$\tilde{p} \geq \frac{\gamma\rho + (1-\gamma)(1-\rho)}{\gamma\rho}\left(\frac{c^F}{(2\rho-1)\gamma} + c^M\right)$$

■

Proof of Lemma 2. For these parameter values, $\tilde{p}$ is such that both Constraint (1) and Constraint (2) are satisfied. This means that if the middleman has induced effort by the farmer in the first stage, he will always exert effort himself in the second stage regardless of the signal received. His expected payoff from inducing the farmer to exert effort in the first stage will therefore equal:

$$\gamma p^H + (1-\gamma)p^L - (\gamma\rho + (1-\gamma)(1-\rho))\left(\frac{c^F}{(2\rho-1)\gamma}\right) - c^M$$

If he does not induce effort in the farmer, then only low-quality goods will be produced. In this case he will pay the farmer the value of his outside option (normalized to zero) regardless of the signal and will never exert effort himself in the second stage. His expected profit in this case will equal p^L. He will therefore choose to induce effort in the first stage when the above expression is at least as large as p^L, which will be true when:

$$\tilde{p} \geq \frac{\gamma\rho + (1-\gamma)(1-\rho)}{\gamma}\left(\frac{c^F}{(2\rho-1)\gamma}\right) + \frac{c^M}{\gamma}$$

■

Proof of Proposition 1(a). First, we must demonstrate that, for these parameter values, the relevant constraints on $\tilde{p}$, are ordered as shown in Figure 1.

1. Constraint 4 will be satisfied for lower values of $\tilde{p}$ than Constraint 2 if:

$$c^M\left(\frac{\gamma(1-\rho)+(1-\gamma)\rho}{\gamma(1-\rho)}\right) > \frac{\gamma\rho+(1-\gamma)(1-\rho)}{\gamma}\left(\frac{c^F}{(2\rho-1)\gamma}\right)+\frac{c^M}{\gamma}$$

$$c^M\left(\frac{\gamma(1-\rho)+(1-\gamma)\rho}{(1-\rho)}-1\right) > \frac{\gamma\rho+(1-\gamma)(1-\rho)}{(2\rho-1)\gamma}c^F$$

$$c^M\left(\frac{(2\rho-1)(1-\gamma)}{(1-\rho)}\right) > \frac{\gamma\rho+(1-\gamma)(1-\rho)}{(2\rho-1)\gamma}c^F$$

   This will be true when:

$$\frac{c^M}{c^F} > \left(\frac{\gamma\rho+(1-\gamma)(1-\rho)}{(2\rho-1)\gamma}\right)\left(\frac{(1-\rho)}{(2\rho-1)(1-\gamma)}\right)$$

2. Constraint 3 will be satisfied for lower values of $\tilde{p}$ than Constraint 4 if:

$$\frac{\gamma\rho+(1-\gamma)(1-\rho)}{\gamma}\left(\frac{c^F}{(2\rho-1)\gamma}\right)+\frac{c^M}{\gamma} > \frac{\gamma\rho+(1-\gamma)(1-\rho)}{\gamma\rho}\left(\frac{c^F}{(2\rho-1)\gamma}+c^M\right)$$

$$\left(\frac{\rho-\gamma\rho-(1-\gamma)(1-\rho)}{\rho}\right)c^M > \left(\frac{(1-\rho)(\gamma\rho+(1-\gamma)(1-\rho))}{(2\rho-1)\gamma\rho}\right)c^F$$

   This will be true when:

$$\frac{c^M}{c^F} > \left(\frac{\gamma\rho+(1-\gamma)(1-\rho)}{(2\rho-1)\gamma}\right)\left(\frac{(1-\rho)}{(2\rho-1)(1-\gamma)}\right)$$

3. Constraint 1 will be satisfied for lower values of $\tilde{p}$ than Constraint 3 if:

$$\frac{\gamma\rho+(1-\gamma)(1-\rho)}{\gamma\rho}\left(\frac{c^F}{(2\rho-1)\gamma}+c^M\right) > c^M\left(\frac{\gamma\rho+(1-\gamma)(1-\rho)}{\gamma\rho}\right)$$

   This will be the case for all possible parameter values as

$$\frac{\gamma\rho+(1-\gamma)(1-\rho)}{\gamma\rho}\left(\frac{c^F}{(2\rho-1)\gamma}\right) > 0$$

For low levels of $\tilde{p}$, Constraint 1 will not be satisfied. As $\tilde{p}$ increases, Constraint 1 will be satisfied, but Constraint 3 will still not be satisfied and therefore only low-quality goods will be produced. As established in Lemma 1, once Constraint 3 and Constraint 1 are satisfied, then partial effort will be exerted. As $\tilde{p}$ continues to increase, once Constraint 2 is satisfied, Constraint 4 will already have been satisfied and therefore at this stage (as established in Lemma 2), full effort will be exerted.

■

PROOF OF PROPOSITION 1(b). The conditions for the order of the inequalities shown in (i) and (ii) above are the same for each. Therefore, the ordering will now be reversed, with the exception of Constraint 1 which is always the easiest constraint to satisfy. Therefore, for these parameter values, the constraints will be in the order shown in Figure 2. As Constraint 4 will be satisfied at lower values of $\tilde{p}$ than Constraint 3, and Constraint 2 will also be satisfied at this point, then partial effort will never be exerted. Once Constraint 4 is satisfied, full effort will be exerted.

■

PROOF OF LEMMA 3. For these parameter values, $\tilde{p}$ is such that Constraint (1) is satisfied but Constraint (2) is not satisfied. This means that if the middleman has exerted effort in the first stage, he will also exert effort in the second stage only if a signal of high quality has been received. His expected payoff from exerting effort in the first stage will therefore equal:

$$\gamma\left[\rho\left(p^H - c^M\right) + (1-\rho)p^L\right] + (1-\gamma)\left[p^L - (1-\rho)c^M\right] - c^F$$

If he does not exert effort in the first stage, then only low-quality goods will be produced. In this case he will incur no costs of producing high quality in either stage of production and his expected profit in this case will equal p^L. He will therefore choose to exert effort in the first stage when the above expression is at least as large as p^L, which will be true when

$$\tilde{p} \geq \frac{c^F}{\gamma\rho} + \left(\frac{\gamma\rho + (1-\gamma)(1-\rho)}{\gamma\rho}\right)c^M$$

■

PROOF OF LEMMA 4. For these parameter values, $\tilde{p}$ is such that both Constraint (1) and Constraint (2) are satisfied. This means that if the middleman has exerted effort in the first stage, he will always exert effort himself in the second stage regardless of the signal received. His expected payoff from exerting effort in the first stage will therefore equal:

$$\gamma p^H + (1-\gamma)p^L - c^F - c^M$$

If he does not exert effort in the first stage, then only low-quality goods will be produced. In this case he will incur no costs of producing high quality in either stage of production and his expected profit in this case will equal p^L. He will therefore choose to exert effort in the first stage when the above expression is at least as large as p^L, which will be true when:

$$\tilde{p} \geq \frac{c^F + c^M}{\gamma}$$

■

PROOF OF PROPOSITION 2(a). First, we must demonstrate that, for these parameter values, the relevant constraints on $\tilde{p}$, are ordered as shown in Figure 3.

1. Constraint 6 will be satisfied for lower values of $\tilde{p}$ than Constraint 2 if:

$$c^M\left(\frac{\gamma(1-\rho)+(1-\gamma)\rho}{\gamma(1-\rho)}\right) > \frac{c^F+c^M}{\gamma}$$

$$c^M\left(\frac{\gamma(1-\rho)+(1-\gamma)\rho-(1-\rho)}{\gamma(1-\rho)}\right) > \frac{c^F}{\gamma}$$

   This will be true when:

$$\frac{c^M}{c^F} > \left(\frac{(1-\rho)}{(2\rho-1)(1-\gamma)}\right)$$

2. Constraint 5 will be satisfied for lower values of $\tilde{p}$ than Constraint 6 if:

$$\frac{c^F+c^M}{\gamma} > \frac{c^F}{\gamma\rho}+\left(\frac{\gamma\rho+(1-\gamma)(1-\rho)}{\gamma\rho}\right)c^M$$

$$\rho c^M-(\gamma\rho+(1-\gamma)(1-\rho))c^M > c^F-\rho c^F$$

   This will be true when:

$$\frac{c^M}{c^F} > \left(\frac{(1-\rho)}{(2\rho-1)(1-\gamma)}\right)$$

3. Constraint 1 will be satisfied for lower values of $\tilde{p}$ than Constraint 5 if:

$$\frac{c^F}{\gamma\rho}+\left(\frac{\gamma\rho+(1-\gamma)(1-\rho)}{\gamma\rho}\right)c^M > c^M\left(\frac{\gamma\rho+(1-\gamma)(1-\rho)}{\gamma\rho}\right)$$

   This will be the case for all possible parameter values as

$$\frac{c^F}{\gamma\rho} > 0$$

For low levels of $\tilde{p}$, Constraint 1 will not be satisfied. As $\tilde{p}$ increases, Constraint 1 will be satisfied, but Constraint 5 will still not be satisfied and therefore only low-quality goods will be produced. As established in Lemma 3, once Constraint 5 and Constraint 1 are satisfied, then partial effort will be exerted. As $\tilde{p}$ continues to increase, once Constraint 2 is satisfied, Constraint 6 will already have been satisfied and therefore at this stage (as established in Lemma 4), full effort will be exerted.

■

PROOF OF PROPOSITION 2(b). The conditions for the order of the inequalities shown in (i) and (ii) above are the same for each. Therefore, the ordering of constraints will now be reversed, with the exception of Constraint 1 which is always the easiest constraint to satisfy. Therefore, for these parameter values, the constraints will be in the order shown in Figure 4. As Constraint 6 will be satisfied at lower values of $\tilde{p}$ than Constraint 5, and Constraint 2 will also be satisfied at this point, then partial effort will never be exerted. Once Constraint 6 is satisfied, full effort will be exerted.

■

Proof of Proposition 3. Scenario 1: For these parameter values, as shown previously, the ordering of the constraints for the two-agent case and single-agent case separately are as in Figure 1 and Figure 3, respectively. We therefore only need to show that Constraint 5 will be satisfied for lower values of $\tilde{p}$ than Constraint 3. This will be true when the following is greater than zero:

$$\frac{c^F}{\gamma\rho} + \left(\frac{\gamma\rho + (1-\gamma)(1-\rho)}{\gamma\rho}\right)c^M - \left(\frac{\gamma\rho + (1-\gamma)(1-\rho)}{\gamma\rho}\left(\frac{c^F}{(2\rho-1)\gamma} + c^M\right)\right) =$$

$$\frac{1-\rho}{\gamma^2\rho(2\rho-1)}c^F > 0$$

Scenario 2: For these parameter values, the ordering of the constraints for the two-agent case and single-agent case separately are as in Figure 2 and Figure 3, respectively. Therefore, the combined ordering must be as shown in Figure 6. Scenario 3: For these parameter values, the ordering of the constraints for the two-agent case and single-agent case separately are as in Figure 2 and Figure 4, respectively. We therefore only need to show that Constraint 6 will be satisfied for lower values of $\tilde{p}$ than Constraint 4. This will be true when the following is greater than zero:

$$\frac{c^F + c^M}{\gamma} - \left(\frac{\gamma\rho + (1-\gamma)(1-\rho)}{\gamma}\left(\frac{c^F}{(2\rho-1)\gamma}\right) + \frac{c^M}{\gamma}\right) = \frac{1-\rho}{\gamma^2(2\rho-1)}c^F > 0$$

■