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Contracts for Grain Biosecurity and Grain Quality

Hoda Abougamos*, Ben White and Rohan Sadler

School of Agriculture and Resource Economics, University of Western Australia, Perth, Western Australia, Australia.

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The export of grain from Western Australia depends on a grain supply network that takes grain from farms to port through Cooperative Bulk Handling (CBH) receival and storage sites. The ability of the network to deliver pest free grain to port and ship depends on the quality of grain delivered by farmers and the efficacy of phosphine based fumigation in controlling stored grain pests. Unfortunately, over time, common stored grain pests have developed resistance to phosphine. There is some evidence that phosphine resistance, develops on farm due to inadequate biosecurity management. This paper considers the design of farm biosecurity contracts using a principal agent approach. An optimizing non-linear programming model with different effort levels of Cooperative Bulk Handling (principal) and farmer (agent) is developed to determine: (i) whether the farmer's effort level affect the CBH's profit function, and (ii) whether increasing monitoring effort by the CBH has an impact on farmer's performance on farm. Results show that; (i) the optimal effort level of farmer is higher for perfect information assumption than moral hazard one. Meanwhile, (ii) under moral hazard assumption, when Bulk Handler is engaged in intensive monitoring level, the farmer is engaged in a higher level of effort. Price premium represents the incentive for farmers, while cost-reduction represents the incentive for Grain Bulk Handler.

Key words: Principal-agent model, biosecurity contracts, asymmetric information, stored grain, effort levels, farmer, grain bulk handler.

INTRODUCTION

Biosecurity hazards stemming mainly from invasive alien pests and exotic diseases impose a threat over the production systems worldwide (Vitousek et al., 1996). Such hazards can potentially result in significant economic losses; especially for agricultural producers in regions infested with pests or diseases. The consequences might extend over individual farmers to have epidemic effect on the agricultural market through non-sustainability in supply and higher prices in demand. Such epidemic impacts are non-ignorable. For example, the annual costs of arthropods are estimated to account for $15.9 billion in US, $0.96 billion in UK, $0.94 billion in Australia, $1.0 billion in South Africa, $16.8 billion in India and $8.5 billion in Brazil. What makes the problem more complicated and have more potential to increase rapidly is the expansion in trade globalization (Pimentel et al., 2001).

Meanwhile, food safety and quality have become significant concerns for consumers' worldwide (Gaaloul et al., 2011). Therefore, achieving and maintaining high quality food standards have been progressed dramatically. In terms of remarkable progress in food

*Corresponding author. E-mail: hoda.ragab@gmail.com

quality approach, the cereal industry has occupied a major portion of such a devastating improvement. Such concerns can have a significant impact on the supply markets; especially when cereals represent a major produce and export as in Australia (Arvanitoyannis and Traikou, 2005; Bertolini, Bevilacqua, and Massini, 2006).

Wheat is Australia's most important grain crop, worth around $7 billion each year (Australian Bureau of Statistics, 2016). Western Australia (WA) wheat exports were valued at a record of $3 billion in 2014/15; accounts for 46% of Australia's wheat exports; (Department of Agriculture and Food, 2016). Engaging in investment (high-quality storage infrastructure) and actions (effective fumigation) can ensure a standard of grain biosecurity that avoids significant loss of grain value through quality deterioration; and assists in maintaining the pest-free status of Australia's grain exports. This may result in enhancing the Australian grain access to markets with stringent standards for stored-grain pests.

As grain moves from farms to port through a transport and storage network, ensuring that grain biosecurity commences on farm and continues at each stage of the network, is vital to the grain supply chain and its final quality. Managing stored grain biosecurity (defined here as ensuring that grain is pest-free for export) depends significantly, on the effective use of phosphine fumigation in sealed stores; in particular for the management of stored grain on farm and through the grain storage and transport network. Since 1984, stored grain industry in WA has been heavily reliant on phosphine to meet export market demand for pest and residue free grain. However, data shows a slow increase in frequency of weak phosphine resistance however, strong resistance, which has recently been detected in intercepted quarantine goods (Chami et al., 2011).

The significance of grain infestation or phosphine resistance problems stems from grain collection in bulk/pool means that, any minor infestation can influence costs of the grain bulk handler and farmers. The potential expansion of phosphine resistance across the grain network may result in its replacement with other fumigants as Carbon Dioxide, which costs 5 to 10 times as much as phosphine (The State of Queensland, Department of Primary Industries and Fisheries, 2008). Meanwhile, other fumigants can have residues in grain as chemicals and pesticides. Hence, phosphine resistance problem may turn up to a food, if not cured at early stages that might have a major impact on global trade. In an economic model of trade losses that can result from non-efficient pest treatment by phosphine, a $1.3 billion was estimated for an outbreak with Karnal Bunt in Western Australia; one of the most threatening grain pests. Some other pests can lead to yield reduction or increase in production and management/monitoring costs (Australian Grains Industry Alliance, 2008).

A simple systematic grain supply network consists of farmers and grain bulk handler (in our case, is represented by the CBH). A farm operating under a Quality Assurance (QA) scheme is expected to applybiosecurity best practice as specified by the assurance scheme contract between the involved parties, in a most likely principal agent relationship. BFIQ (Better Farm Intelligent Quality) is a QA scheme initiated by the CBH in WA since 2008 to 2009. BFIQ (now called CBH QA) aims to meet export standards and indirectly, benefit farmers by increasing the price-premium for their grain (Safe Quality Food Institute, 2010). In this context, CBH QA provides international customers with additional QA by emphasizing that, the required quality has been achieved on farms through managing/monitoring the planting, harvesting, storage and transport of grain to reduce quality deterioration. Meanwhile, CBH QA helps the industry to manage grain safety and quality risks and hence; reduces management and monitoring costs; and probably enlarges profit level.

In terms of economics and management, three pronged strategy is considered. First, within CBH use existing infrastructure to ensure that, neither infestations nor resistance emerges; second, provide farmers with an incentive to deliver insect free and residue free grain to CBH stores; and third, develop monitoring methods that are able to identify outbreaks of strongly resistant grain beetles quickly and cheaply, to isolate and eradicate the outbreak (Newman, 2011). The paper in hand focuses on the last two strategies.

The aim of this paper is to discuss the possibility of grain quality improvement through contracting between the involved parties; assuming risk-neutrality of different parties. Any downgrading of grain quality because of low effort level of one or more farmers will be shared among all farmers in terms of lower premium levels, which is similar to public good problem. Farmers exert independent effort levels but share an interconnected price. Therefore, the paper determines two issues: (i) whether the farmer's biosecurity effort level exerted on farm affects CBH's profit function, that is, better farmer performance increases CBH's profit; and, (ii) whether an increase in the monitoring effort by CBH has an impact on farmer's biosecurity effort on farm. The study is structured as follows. Section 2 reviews the principal-agent theory under asymmetric information. Section 3 reviews some case studies on the application of the principal-agent model in the presence of asymmetric information problems. Section 4 develops the farm biosecurity contract model. Section 5 gives results, and Section 6 concludes.

Literature review on principal-agent theory under asymmetric information

The marketing contract between principal and agent(s) plays an important role in controlling product quality and safety. On one hand, the principal seeks a continuous

supply of safe and good quality products to reduce transaction costs incurred with faulty products. On the other, the agent(s) requires income stability, market security and access to technology and capital. Thus, contracts serve two purposes: they coordinate exchanges in the production process, while providing a portion of control and risk-sharing between the contracting parties/members.

Agents(s) accepting a contract are expected to conform to all requirements of the contract. Nevertheless, it is hard for the principal to measure quality and/or observe directly product properties at delivery time. Accordingly, establishing compliance is difficult. The problem with food risks, when growers/agents know in advance that their production process and final product quality cannot be directly noticed by processors/principals. This results in growers /agents probable use of poor practices, with the probability increasing with the profits to be gained through opportunistic behaviour. Therefore, the difficulty of detection or enforcement of contracts allows the grower/agent to promise the delivery of a safe product but does not fulfil this promise even under contract-terms; representing a moral hazard problem.

Moral hazard or incentive problems stem from asymmetric/imperfect information among members of a firm as agents' actions cannot be observed and hence cannot be contracted upon. Inspection and penalties can to an extent influence grower's behaviour. As penalty increases, the financial risk of breaking rules increases and hence, compliance also increases. Babbage (1835) emphasizes the need for accurate evaluation of the agent's performance in an attempt of setting-up efficient contracts. The general principles of agent's remuneration are linking a considerable part of the agent's wages, to the firm's profit and allocating more advantages for all contributed improvements. However, Barnard (1938) is the first one to define a general theory of incentives in management. He highlights the need to stimulate desired effort levels of the agent and to create the principal relationships within the firm to tackle the necessary imperfectness of incentive contracts. Arrow (1963a) introduces the idea of moral hazard borrowed from the insurance world to the literature on the control of management. Williamson (1975) uses the case of symmetric but non verifiable information between two parties, to develop his transaction costs theory. Grossman and Oliver (1983) model the principal agent relational pattern and hence, achieve the significant context of modern literature on incomplete contracts that stems from asymmetric/imperfect information (Laffont and Martimort, 2002).

Heuth et al. (1999), proposes four possible remedies for the problem of asymmetric information. First, try to monitor the grower/farmer's activities by direct observation in the field. This option could work, if principal's observations could fully reflect the actual performance of the grower according to a previously stated plan. Second, try measuring product's quality and link some portion of the farmer's payment on realized quality. Third, try to find ways to gain more control over farmer's quality related activities by directly specifying one or more inputs that can have direct impact, the final quality. Fourth, by making farmers responsible for bad quality products such as to make the farmer's last payment directly related to downstream price; this will make farmers residual claimants for their poor performance (Heuth et al., 1999).

Our analysis is related to previous literature on principal agent models; addressing food safety through marketing contracts. Harris and Raviv (1976) address a principal agent relationship in which the agent provides a productive input (e.g effort) that cannot be observed by the principal directly. Their results relate to a very specific kind of imperfect monitoring of the agent's action which allows the principal to detect any shirking by the agent with positive probability. Holmstörm (1979) studies efficient contractual agreements between a principal and an agent under different assumptions about what can be observed, and hence contracted upon. He found that when the procedures alone are observable, optimal contracts will be the second best as a result of a moral hazard problem. Therefore, he concluded that contracts can generally be improved by creating additional information systems (as in cost accounting), or by using other available information about the agent's action or the state of nature (Holmstörm, 1979). Meanwhile, Elbasha and Riggs (2003) show that regardless of the orientation of the legal system, the levels of efforts exerted by the principal and the agent are suboptimal when efforts are complements, and ambiguous when efforts are substitutes. The impacts of a policy that forces agents to provide the principal with information about food preparation and handling can improve social welfare, if information is complementary to efforts (Elbasha and Riggs, 2003).

Principals have many strategies for ensuring growers/farmers' delivery of safe food ingredients including the reduction in measurement error through improved diagnosis and motivating suppliers to provide safety signals. In some supply chains, such strategies are either not possible or very expensive. Therefore, designing careful contracts can be a relative inexpensive alternative; while promising a potential for safe food improvement (Starbird, 2005a). Also, Starbird (2005b) uses principal-agent theory to explain the interaction between sampling inspection, failure costs (penalties), and food safety. The sampling inspection policy, the internal failure cost, and the external failure cost were found to have a significant effect on the buyer's willingness to pay for safer food and, hence, on the supplier's willingness to exert the effort required to deliver safe food.

In response to a spinach *E. coli* outbreak in 2006, Western Growers initiated the California Marketing

Agreement that requires all signatory leafy greens handlers to buy product only from farmers, who follow the newly developed Leafy Greens Good Agricultural Practices (GAP). As a result, direct relationships with farmers/agents were based on compliance with production practices and have allowed processors/ principals to become much more involved than before in the production practices (Liang and Jensen, 2008). In contrast, when a principal makes an effort that can impact a product's quality and can be by consumers, this will weaken the grower's/farmer's incentive to apply effort in quality control (Olmos et al., 2011).

Especially relevant to this study are the studies that highlight how the marketing contract between principals and growers/farmers affects agricultural production. Several studies have explored the effects of contracting using theoretical and empirical approaches. Liang and Jensen (2008) finds that, the optimal premium is higher and the base payment is lower under the contract with a marketing agreement and the processor earns less under the contract with a marketing agreement.

Until now, however, no formal studies of agricultural contracts have examined the relationship between grain bulk handler (CBH Ltd as the principal) and grain farmer (as an agent) in a principal-agent context within a grain supply chain, with the objective of improving final grain quality. Hence, the contribution of this paper is to determine two issues: (i) whether the farmer's effort level affects CBH's profit function, that is, better farmer performance increases CBH's profit; and, (ii) whether increased monitoring effort by the CBH has an impact on farmer's biosecurity effort on farm. The objective of the model proposed in this paper is to examine how a monitoring strategy, as one of the sated above remedies for asymmetric information problems can influence the behaviour of growers/farmers with respect to grain production quality. Such kind of information may help in designing efficient incentive contracts in the context of the principal agent theory.

METHODOLOGY

The current contract between grain producers and bulk handler is outlined in the Grain Operations Harvest Guide (CBH, 2011). The ability of grain handler, such as CBH, to contract for grain that is insect and other contaminant free is complicated by twin problems, asymmetric information and moral hazard. Asymmetric information implies that the farmer knows how the grain has been managed in storage and on farm, but CBH cannot observe that directly. The related problem of moral hazard is where the farmer does not have an incentive to manage stored grain according to industry best practice. There is a widespread evidence that standards of stored grain management for biosecurity are not universally applied (Taylor and Slattery, 2010). The problem that CBH faces is one of a principal agent one; where CBH devises a grain supply contract that pays producers a price premium for clean grain. Indirectly this may induce farmers to increase their biosecurity efforts on farm. However, to reinforce this reaction, CBH must also engage in grain sampling for live insects and pests at receival sites.

The Principal-Agent model in this paper assumes that a profit maximising risk neutral bulk handler (CBH) procures grain from a group of farmers. The aim of CBH is to maximise profit by selling grain to the world market at price P_W, less biosecurity costs. CBH's expected costs depend on the effort level exerted by farmers to deliver clean grain, monitoring costs for CBH and the price premium paid as an incentive for farmers to deliver un-infested (clean) grain. The CBH is trying to reduce the costs incurred within a grain supply network by reducing/eliminating infested grain access to bulk storage and transport network. Prices paid to farmers by CBH are constrained by farmers' participation and incentive constraints.

Model Overview

A mathematical grain quality model based on the Principal-Agent theory is used to discuss how the effort level exerted on farm can have an effect on the final grain quality and farmer's net profit, gained from selling grain to CBH. The grain quality model is written and solved in General Algebraic Modelling System (GAMS; GAMS Development Corporation 2006). Three scenarios for a grain quality model will be discussed in the following section. The three scenarios formulate the relationship between a farmer and CBH in a principal-agent context over a single year. The farmer and CBH can choose an effort level that ranges between zero (no-effort) and one (all effort required to reach grain high quality).

According to the effort level chosen, grain quality varies. At one hand, the effort level on farm is stimulated by price premiums received by farmers after grain delivery and inspection at CBH. The farmer's effort includes biosecurity activities performed to reach grain-quality desired in a BFIQ context. At the other hand, the CBH effort level is stimulated by higher profits received from exporting good-quality grain overseas. Free of infestations grain results in higher price premium/profit for CBH and vice-versa. CBH's effort includes monitoring activities to inspect the quality of grain delivered by farmers. Grain price with/without premium paid to farmers is constrained by participation and incentive constraints. Monitoring costs at CBH plus grain-price paid to farmers influence the objective function.

Scenario 1: Optimal contract design under symmetric information

The assumption of complete information entitles that the farmer's effort level is verifiable by CBH, and hence, CBH can compensate the farmer directly for his effort. The farmer knows in advance (before signing the contract with the CBH) that she will be paid according to her effort level. Effort is represented by an index such that $0 \leq e_f \leq 1$

The economic decision variables of the model are the farmer's effort and its corresponding price premium paid by CBH. GAMS software is used to trade-off between different verifiable/observable biosecurity effort levels exerted on farms and the corresponding farmer's price premiums paid by CBH. The difference between world prices paid to CBH for grain exported overseas minus the prices paid to farmer either with/without price premium (according to grain quality) minus the cost of infestation incurred by CBH will make up the CBH profit maximization problem.

Therefore, the profit maximization problem from the point of view of CBH can be set out as follows:
Maximise with respect to (e_f, p_f):

$$\left(p_w - e_f\,(1+\theta)p_f - \left(1-e_f\right)p_f - \left(1-e_f\right)c^{inf}\right) \quad (1)$$

Where (p_w) is the world wheat price less the expected price paid for high quality grain ($e_f\,(1+\theta)p_f$) and the expected price paid for low-quality grain ($\left(1-e_f\right)p_f$) less the cost of infestation that CBH

incurred, because of low grain quality ($(1-e_f)c^{inf}$). The farmer's incentive to apply effort depends on the profit derived from selling grain to CBH. There are two constraints: a participation constraint and an incentive constraint. The participation constraint (or individual rationality constraint) that ensures farmer's expected profit is not reduced by contracting with CBH is:

$$e_f(1+\theta)p_f + (1-e_f)p_f - c_f(e_f) \geq 0 \quad (2)$$

The *incentive constraint* ensures that expected profit is not reduced by increasing effort. This constraint is the derivative of the participation constraint:

$$\theta p_f \geq c_f'(e_f) \quad (3)$$

The first best effort level under perfect information when CBH can verify farmer's effort is given by the first order condition:

$$\left(c^{inf} - c_f'(e_f)\right) = 0 \quad (4)$$

The equation above implies that the first best will be obtained by equating the CBH's marginal value; represented as savings in infestation minus the cost that should have been paid in case the farmer puts lower/no effort level instead, with the farmer's marginal cost of doing effort.

Scenario 2: Optimal contract design under asymmetric information and cbh's zero monitoring cost

The model setup remains the same but due to asymmetric information; the farmer's effort is non-verifiable (Laffont and Martimort 2002). However, CBH can monitor (inspect) grain and pay the farmer according to grain quality. CBH does not incur any monitoring cost to detect a farmer's effort; therefore, CBH chooses to put the highest effort level to monitor the farmer's performance. The economic decision variables of the model are the effort level of the farmer and its corresponding price premium paid by CBH plus the monitoring effort level done by CBH to detect grain quality and to pay the farmer accordingly.

GAMS software is used to trade-off between different non-verifiable effort levels exerted on farms, the monitoring effort at CBH and the price premiums paid to farmer. The main objective of the model is to find the optimum effort level of the farmer and CBH that will increase the CBH profits. CBH profit is reduced by prices paid to farmers either with/without price premium (according to grain quality), plus the cost of grain infestation. Therefore, the profit maximization problem from the point of view of CBH can be set out as follows:

Maximise with respect to (e_f , p_f):

$$\left(p_w - e_m\, e_f\, (1+\theta)\, p_f - e_m(1-e_f)p_f - (1-e_f)c^{inf}\right) \quad (5)$$

The CBH's profit is the world price (p_w) for exported grain minus a high price (price premium) paid to the farmer ($e_m\, e_f\, (1+\theta)\, p_f$) after monitoring her effort level to be satisfactory minus the non-premium price paid to the lower farmer's effort observed by CBH ($e_m(1-e_f)p_f$) minus the cost paid by CBH as a consequence of having infested crop ($(1-e_f)c^{inf}$). The optimal effort level (second-best) exerted under asymmetric information assumption where the farmer's effort level is unverifiable but CBH can detect grain quality without incurring extra cost is given by the following necessary condition:

$$\left(c^{inf} - c_f'(e_f) - e_f\, c_f''(e_f)\right) = 0 \quad (6)$$

The equation above implies that the second best will be obtained by equating the CBH's marginal value represented by savings in the cost of infestation it should have paid otherwise with the farmer's marginal cost of doing effort plus a third term. The third term of the equation represents how much the change in the rate of farmer's effort will change the farmer biosecurity cost on farm. A small change in farmer's effort level will result in higher impact on CBH's marginal profit

Scenario 3: Optimal contract design under asymmetric information and CBH's payable monitoring cost

The third scenario which is the more complicated case deals with the farmer and CBH under moral hazard assumption; where the farmer can manipulate her effort level. CBH needs to exert some effort to monitor the farmer's performance; while it incurs monitoring cost. However, CBH will not always succeed in detecting her accurate level of effort. Consequently, CBH might commit type I (classifies non-infested crop as infested) or type II (classifies infested crop as non-infested) errors when judging a farmer's performance. The possibilities are summarised in Table 1. The economic decision variables of this scenario are the effort level of the farmer and its corresponding price premium paid by CBH, plus the monitoring effort level of CBH.

The profit maximization problem from the point of view of CBH can be set out as follows:

Maximise with respect to (e_f, e_m, p_f):

$$\{p_w - (\alpha^s(e_f, e_m)(1+\theta)p_f) - \left((1-\alpha^s)(e_f, e_m)\right)p_f - c^{inf}(e_f, e_m) - c_m e_m\} \quad (7)$$

CBH profit is reduced by the price paid to farmer plus the monitoring cost and the cost of infestation.

The probability of CBH paying the price premium is:

$$\alpha^s(e_f, e_m) = e_f\, e_m + (1-e_f)(1-e_m) \quad (8)$$

The probability of not paying a premium to the farmer:

$$1 - \alpha^s(e_f, e_m) = e_f(1-e_m) + (1-e_f)e_m \quad (9)$$

The expected cost of infested grain is:

$$c^{inf}(e_f, e_m) = (1-e_f)e_m\, c^{inf}{}_0 + (1-e_f)(1-e_m)c^{inf}{}_1 \quad (10)$$

The first term on the right hand side of the equation is an expected cost when an infested crop is detected and is segregated. The second term is the expected cost when infested crop is not detected and is allowed to infest a batch of grain at the receival site. It is expected that:

$$c^{inf}{}_0 < c^{inf}{}_1 \quad (11)$$

Table 1. Grain status detection events.

Farm biosecurity state	CBH detects grain status	
	Detected	**Not detected**
Insect Free	$e^f e^m$	$e^f(1-e^m)$
Infested	$(1-e^f)e^m$	$(1-e^f)(1-e^m)$

Table 2. Model parameters.

Parameter or function	Value of parameter or function ($/tonne)
Export Wheat Price 2008 ($\boldsymbol{p_w}$)	326
Farmer's Reserve Wheat Price ($\boldsymbol{p^f}$)	$0.7\ p_w$
$\boldsymbol{C_f(e^f) = \beta_0\left(\frac{1}{1-e^f}\right)^{\beta_1}}$	$\beta_0 = 6.17;\ \beta_1\ 0.365961$
$\boldsymbol{C_m(e^m) = \phi_0\left(\frac{1}{1-e^m}\right)^{\phi_1}}$	$\phi_0 = 10;\ \phi_1 = 0.5$
$\boldsymbol{C_0, C_1}$	$C_0 = 30, C_1 = 120$

That is, when infestation is detected and infested crop is segregated from other non-infested crop, losses or costs incurred by the CBH will be less than when it is not detected and infestation will permeate the whole crop. The condition for an optimal selection of biosecurity effort of the farmer and the monitoring effort of CBH is given by:

$$\frac{c^{inf}\ e_m + c_m^{'} e_m}{c^{inf}\ e_f + \gamma c_f^{''}(e_f)} = \frac{\alpha^s(e_m) - 2\gamma}{\alpha^s(e_f)} \quad (12)$$

The previous equation shows that the marginal expected cost of infested crop is equal to the corresponding increase in the probability of crop being assessed as 'non-infested'.
For a given monitoring scheme for CBH, the farmer exerts the following effort:

$$-c^{inf}\ e_f - c_f^{'}(e_f) - h(e_f, e_m)c_f^{''}(e_f) = 0 \quad (13)$$

Where;

$$h(e_f, e_m) = -\frac{\alpha^s(e_f,\ e_m)}{\alpha^s(e_f)}$$

Parameter values for the model

The model has a relatively small number of parameters (Table 2); most are straightforward, such as the WA grain price. The price of rejected grain or infested grain is set as a parameter in relation to the WA grain price. The only non-linear elements in the model are the costs of farmer biosecurity efforts and CBH monitoring efforts. These functions are calibrated from available data (Taylor and Dibley, 2009, CRC70096). The cost of infested grain involves two terms: when infested grain is identified, then it can be separated and treated at a relatively low cost. However, a more substantial cost is incurred when infested grain is not detected and is combined in a larger batch; to impose a significant problem to the whole grain bulk.

Model output

The model's optimal solution includes effort level exerted by farmer and CBH. The more effort done on farm, the less effort will be required at CBH and better grain quality will result and vice-versa. Each model scenario generates different profit for CBH. Given the grain prices paid to farmers (with/without premium), CBH's profit associated with each grain-quality scenario (i.e. objective function value) is calculated. Optimal effort levels for farmer and CBH and their resulting profit values for various grain-quality scenarios are then compared to address the research questions.

RESULTS

The effort levels within the three scenarios and their associated returns are compared to highlight the effect of the asymmetric information problem between CBH and farmer (Figures 1 and 2). The results give a clear message that, asymmetric information reduces the profits of both the farmer and CBH. New technology that reduces the cost of monitoring to CBH is beneficial as it reduces CBH costs; and induces a higher level of biosecurity effort by the farmer.

Consider the perfect information result (Scenario 1); CBH is able to detect infested grain at no cost; and therefore selects e_m =1. Also CBH is able to contract on the level of farmer's effort. Results (of scenario 2 and 3) show a more complicated case; where CBH depends on a price premium θ (or cost-discount) to provide farmer

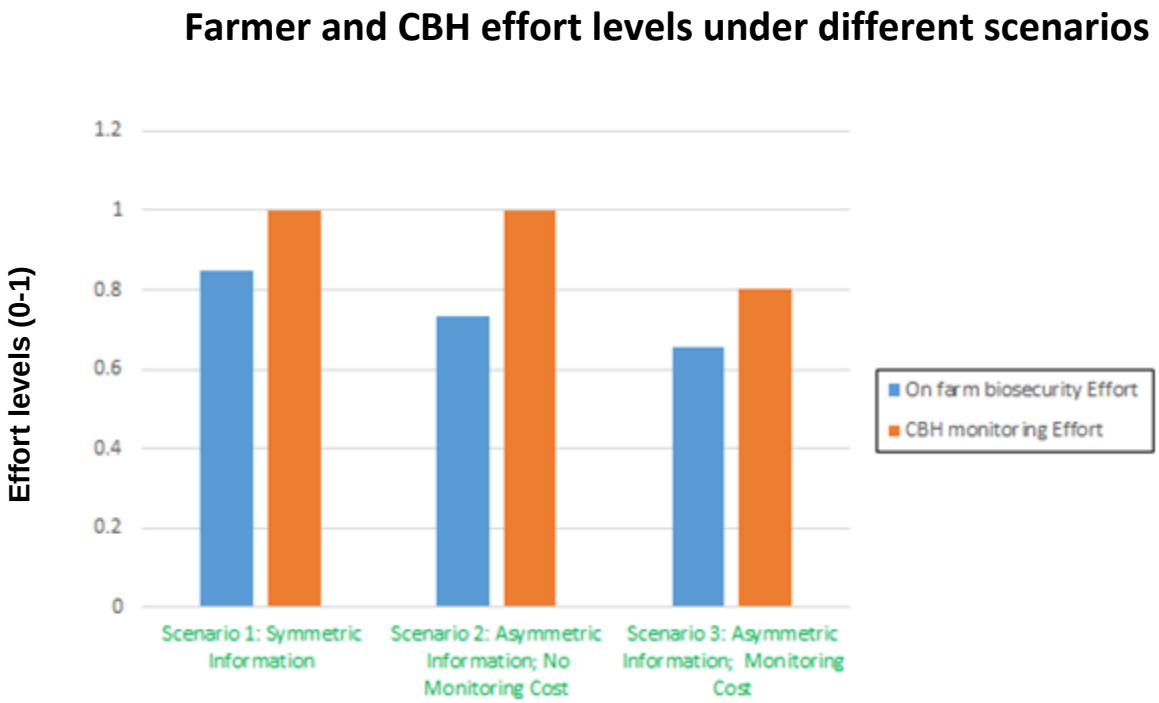

Figure 1. Effort levels exerted by farmer and CBH under scenarios 1, 2 and 3.

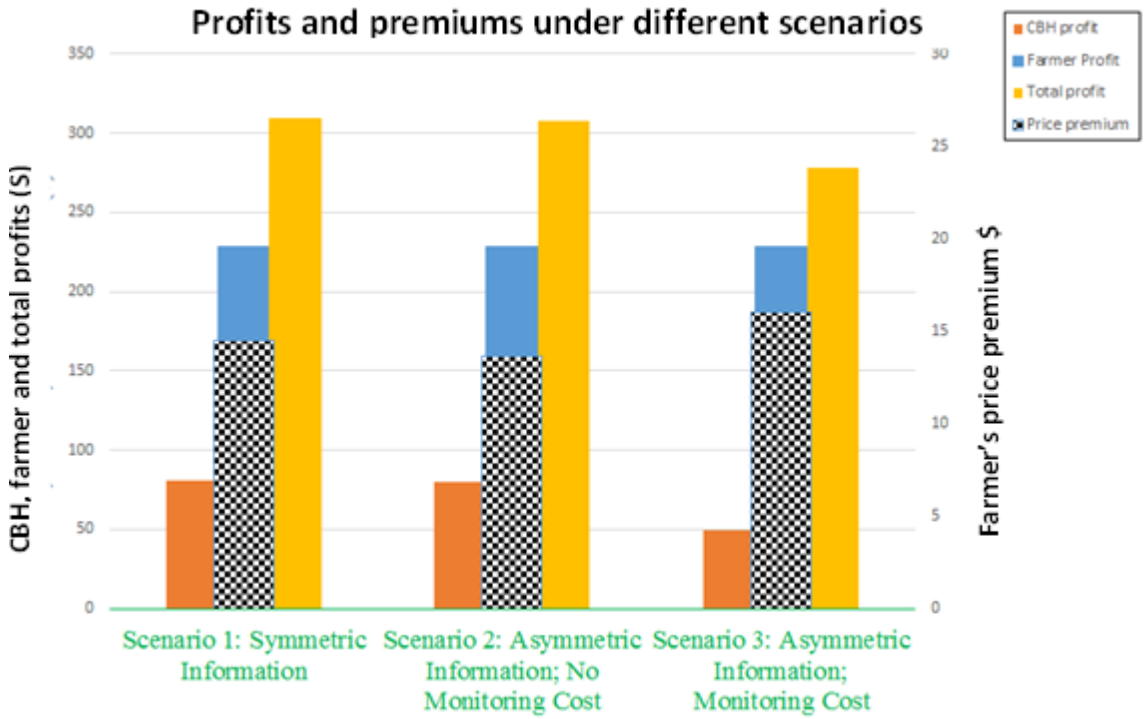

Figure 2. Farmer's Price premium and farmer and CBH's profits under scenarios 1, 2 and 3.

with an incentive to deliver insect-free grain. However, the incentive for on farm effort declines in Scenario 3; when the cost of CBH monitoring dictates that CBH engages in imperfect monitoring and occasionally

mis-classifies grain as infested (when not-infested) and vice-versa. These errors of classification reduce the incentives of farmers to exert biosecurity effort.

Figures 1 and 2 illustrate the cases of different information types and effort levels that the biosecurity contract model produces. CBH as the principal offers a contract to a farmer, which includes a price premium; when clean grain is detected. The contract fixes a level of monitoring of grain quality and targets a level of farm effort; that entails labor and material costs related to managing biosecurity on farms. Figure 1 shows clearly the decrease in farmer's effort level on farm between the three scenarios.

Under asymmetric information, there is a probability of mis-classification of wheat quality by CBH which exerts the least biosecurity effort level. This reaction reflects how significant it is to have the correct monitoring effort level at CBH; that gives more confidence to farmer where effort level will be correctly rewarded and paid for. In addition, a comparison between the three scenarios show the lower monitoring effort level of CBH because of the accompanied monitoring cost. A technological advancement that may result in reducing monitoring cost for CBH, may lead to higher grain quality and more profits for farmer and CBH.

Figure 2 indicates the lower CBH profit level under scenario 3 because of the higher incurred losses with the asymmetric information scenario between CBH and farmer; which cannot be correctly detected with the high monitoring cost. Farmer's profit has not been actually changed between the three scenarios. This might be a significant reason of farmer's manipulation; who does not need to exert much effort if the profit will not be affected. A fair system of evaluating farmer's effort can be a stimulator to deliver a high quality grain to CBH. A higher price premium paid to farmer under scenario 3 shows a good way of encouragement to deliver grain that is pest free; but does not guarantee it. Better evaluation methods for grain quality may help encourage higher biosecurity effort levels on farms.

DISCUSSION AND CONCLUSION

The main findings of the paper can be summarized as follows: (1) Asymmetric information, relating to grain quality and in particular the effort level that the farmer applies to grain biosecurity management on farm, imposes a cost on CBH and hence; reduces its profit. (2) The CBH's ability to monitor grain's quality delivered to their receival sites encourages the farmer to exert more biosecurity effort on farm. The results of the three scenarios described under grain quality model show that, asymmetric information between CBH and farmer reduces the CBH's profits. New technology that reduces the cost of monitoring to CBH is beneficial as it induces a higher detection level at CBH; and consequently a higher effort level on farm and a resulting good quality of grain. The contract between CBH and farmer includes a price premium related to the freedom of grain from any pests. The level of effort on farm entails labour and material costs related to managing biosecurity on farm.

This paper presents some provisional results on the design of contracts for grain quality. The realistic scenario; where farm effort is non-verifiable and CBH monitoring is costly requires that CBH pays a price premium to the farmer of around 5% over the reserve price. Farmer's and CBH's monitoring practices are considered substitutable. The more effort exerted by farmer on farms, the higher the grain quality will be and the less effort required by CBH, and vice-versa. The model can be further developed by including contracting over farm grain store investment. This would then allow farmers to signal their intention to store grain in a way that reduces the probability of infestation. In addition, some other factors that result in grain quality deterioration; rather than misuse of phosphine, might be included to measure for their impacts on the grain network.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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