Imperfect Signals and Product Safety Disclosure: A Shepherd’s Dilemma

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Abstract

We study dynamic markets where product safety is unobserved by consumers. Perfect, but costly, audits and an exogenous noisy signal can provide information regarding seller type. Without the noisy signal, sellers do not disclose product safety without auditing. If audits are too expensive, a pooling equilibrium can result in consumption of unsafe goods. Even a noisy quality signal perfectly identifies unsafe goods by giving sellers incentives to disclose type without audits. Introducing a signal helps buyers, but its effect on sellers is ambiguous. Even if sellers benefit, they always suffer from increases in precision. As an illustration, we examine equilibrium impacts of using recent technological advances in disease forecasting in an international livestock market.

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1 Introduction

We model repeated interactions between a buyer and sellers of a product whose quality cannot be easily observed. We suppose that while the buyer values high quality, she would be willing to pay to avoid purchasing a low-quality product. A seller knows the quality of his good in each period. From the buyer’s perspective, however, quality is a credence characteristic: Even after purchase, she cannot identify it without cost.\(^1\) Even after consumption, if the buyer experiences a bad outcome she cannot trace the damage to its origin. Examples of such markets include those where product safety is a concern (e.g., tainted food, or the use of toxic chemicals in children’s toys), or those involving procurement of a team’s output (a low-quality contributor may ruin the joint output, but it can be difficult to trace the damage to a specific individual). If expected harm is sufficiently high, it is Pareto optimal for sellers to disclose low quality before consumption occurs.

Relying on sellers’ goodwill or reputation for honesty may not be sufficient for optimal disclosure.\(^2\) Nor may regulations guarantee disclosure, if (perhaps due to political reasons) they lack sufficient penalties or enforcement capacity.\(^3\) Other mechanisms for revealing quality commonly discussed in the literature (warranties, liability rules, and signaling through pricing or advertising) also have their limitations. Warranties and liability rules may not ensure optimal disclosure since, even if causality could be established, the damage may far exceed a seller’s ability to pay before going bankrupt.\(^4\) Also, firms may be unable to signal quality through price or advertising if they lack market power or if consumers cannot distinguish quality after consumption.\(^5\)

Recognizing these limitations, our work differs from previous approaches by shifting the focus from the seller from the buyer. We analyze the problem faced by a buyer engaging with competitive sellers of a credence good who have private information regarding quality. Market interactions are repeated, but seller quality is imperfectly persistent. In our initial framework, the only instruments at the buyer’s disposal are a costly test and non-negative payments. (We grant the sellers limited liability to rule out solutions with infrequent audits and large penalties.) Sellers are skeptical, refusing to believe commitments by the buyer to act in a time-inconsistent manner. After characterizing disclosure in equilibrium contracts in this setting, we examine the impact of introducing an exogenous noisy signal of seller quality.\(^6\)

In some cases, noisy signals may exist regarding quality before purchase. Lizzeri (1999) and Albano and Lizzeri (2001), for example, discuss the incentives faced by third-party certification institutions. Even if such
intermediaries had perfect access to product information, they can obtain rents by reporting noisy signals to consumers. In agricultural markets, local climatic conditions can provide a noisy signal of quality. In a team production setting, health tests may provide a signal of worker productivity. Similarly, epidemiologic models can provide signals as to where potentially dangerous livestock disease outbreaks are likely to occur. A natural question is to what extent such signals can complement or replace other disclosure mechanisms.

In the emphasis on credence goods, our model differs from the bulk of the product quality literature. However, our model also departs from the standard approaches taken in the credence goods literature as well. In a recent survey, Dulleck and Kerschbamer (2006) describe how this literature has focused on variants of the “mechanic” model. An uninformed consumer can take a problem to an expert. The expert declares the severity of the problem (small or large) and proposes a corresponding treatment (cheap or expensive). In these models consumer utility is only a function of payments and whether the treatment works, not the severity of the underlying problem. In our model, the informed party (seller) only states the severity of the problem. The buyer performs the “treatment” (discarding low-quality products). Thus knowledge of the actual quality is of paramount importance. Nonetheless, our results for the simple one-period problem are similar to those shown by Dulleck and Kerschbamer (2006) in a standard model where the consumer can neither verify the type of treatment nor hold the expert liable for a bad outcome. Markets either break down or sellers receive a flat payment regardless of quality.

Incorporating the possibility of audits allows a third outcome. If the audit is sufficiently cheap, the buyer overcomes the information problem by brute force, auditing all high quality declarations. In either case, quality becomes known in equilibrium, and the buyer never consumes low-quality products.

By expanding the basic model to two periods, our results become more pessimistic. If there is any intertemporal correlation in types a form of the “ratchet” effect influences first-period equilibria, as in Freixas et al. (1985). If audits are sufficiently expensive, fear of future discrimination induces pooling. As a result, quality remains unknown and either the market collapses or the buyer runs the risk of consuming low-quality products. If audits are cheaper, random audits may induce a separating equilibrium by rewarding truthful disclosure.

We then show how a noisy signal between periods can help induce disclosure. Interestingly, the main value of this signal is not to screen out low-quality goods in the sense of Stiglitz (1975). Instead, by breaking the link between current disclosure and future discrimination, it transforms the dynamic game into repeated
static games. As a result, even a noisy signal can induce perfect identification of unsafe goods by enabling a fully separating equilibrium in which producers report safety without auditing. Finally, we examine the welfare implications of introducing a noisy signal. Welfare impacts can be particularly important if sellers have an implicit right to veto a signalling mechanism (e.g., by withholding information necessary to calibrate forecast technology). We identify conditions under which sellers should be willing to provide this information.

Our theoretical model builds on the adverse selection mechanism design literature, combining the costly state verification (CSV) model pioneered by Townsend (1979) with work on noisy signals (e.g., Burdett and Mortensen, 1981; Mason and Sterbenz, 1994; Lizzeri, 1999; Albano and Lizzeri, 2001) and inter-temporally correlated types. Our correlated types model is similar to that pioneered by Baron and Besanko (1984) in the two-period case (later generalized by Battaglini (2005) for infinite repetitions). Whereas these models allow either full commitment or renegotiation-proof contracts, we extend the analysis to cases in which time-inconsistent strategies are not credible.

The CSV model extends earlier results by Akerlof (1970) and others in the analysis of markets with asymmetric information regarding product quality. Specifically, it allows private information to be revealed at a cost. Numerous authors have extended the CSV model into a dynamic framework, focusing on the effect of discount rates (Wang, 2005), equilibria when the informed party’s type is uncorrelated across time (Monnet and Quintin, 2005), and equilibria when the uninformed party is permitted to make time-inconsistent threats or promises (Fernandes and Phelan, 2000). Our model extends this literature by focusing on situations with limited commitment. Unlike the earlier literature, we are thus able to show how CSV may partially overcome the ratchet effect.

If a test is not conducted, the buyer views each seller’s current type as a random variable. Beliefs regarding the seller-specific probability distribution of type are conditioned on a noisy signal. The impact of noisy quality signals on market size has been examined by Mason and Sterbenz (1994) in a static framework. In their model, an endogenous number of sellers can voluntarily undergo a noisy product test. Lizzeri (1999) examines the role of a certifying intermediary that can perfectly observe quality, but send a noisy signal to consumers. Heinkel (1981) and Albano and Lizzeri (2001) examine the effect of a noisy signal on non-repeated interactions in which quality is endogenous. Our model extends these results by examining the impact of an exogenous noisy signal in a dynamic setting that also allows for the simultaneous existence of a perfect testing device.
As an illustration, we examine equilibrium impacts of using recent technological advances in disease forecasting in an international livestock market. Our model captures many of the stylized facts of recent outbreaks of Rift Valley Fever (RVF) in East Africa. RVF is a mosquito-borne livestock disease that can be transmitted to humans through contact with bodily fluids of infected animals. Of particular risk are individuals involved in sacrifice of lambs for Muslim religious ceremonies. The disease is highly feared, potentially causing blindness, miscarriage, and death. For cultural reasons, the Greater Horn of Africa has historically been the preferred source of lambs for the Arabian peninsula. Due to recent RVF outbreaks, however, importing countries have imposed region-wide import bans, with a devastating impact on the rural economy.

Advances in climatic and entomological modeling raise the possibility of using a disease forecasting system as an alternative to regional import bans for preventing the entry of infected lambs into the market (Linthicum et al., 1999; Anyamba and Tucker, 2005). Local data on RVF episodes is necessary to calibrate forecast models. The presence of RVF in a flock is often evident to a producer through visible symptoms in the ewes, but not in the lambs brought to market (Martin et al., 2006). Thus, producer cooperation is essential for the forecast system to be put into place. In spite of potential benefits, however, producers are reluctant to provide this information. Shepherds face a dilemma of disclosing disease exposure and risking individual blacklists or not disclosing and risking regional boycotts.

The problem is reminiscent of Akerlof’s (1970) lemons model. Shepherds have private information regarding their flock’s health. For a seller to disclose the true health status, it must be incentive compatible for him to do so. In a one-period model, sellers would truthfully report information if they all received the same price. If the proportion of diseased animals is too high, however, this strategy gives the buyer an expected loss, and the market collapses. Similar to the role played by auditing firm accounts (e.g., Townsend, 1979), random veterinary testing can play a role in reducing the impact of the information asymmetry.

In East African livestock markets, however, we neither observe random tests nor revelation of animal health. Instead, in some years sellers are treated equally yet do not reveal information, while in others the market breaks down completely. By extending the literature to allow for multi-period interactions with intertemporal correlation of agent types, we show how such outcomes may arise. By revealing disease exposure today, sellers signal a relatively high chance of future exposure. If sellers believe the buyer will use this information against them, incentive compatibility constraints are more severe than in the static problem.
We show plausible conditions under which information rents are so high that owners of healthy flocks are tempted to claim their flocks are diseased. In such cases, full disclosure is not incentive compatible, and pooling arises in which all types of sellers make the same claim.

The rest of the paper is structured as follows. In the next section we provide a brief background of recent experience with RVF in East Africa. In Section 3, we set up a model specifying the basic information structure of the market. In the subsequent two sections, we characterize Perfect Bayesian Equilibrium outcomes of the market first without (Section 4) then with (Section 5) a forecast. In Section 6, we conclude with policy implications. Proofs are provided in an appendix.

2 Rift Valley Fever

Rift Valley Fever is a viral disease first identified in livestock in Kenya in 1931 (Daubney et al., 1931). Transmission to humans can occur by contact with blood or bodily fluid from infected animals (WHO, 1998). Although most cases in humans are fairly benign, RVF can lead to blindness, hemorrhagic fever, miscarriage, and death. It has thus been a source of widespread public panic (BBC News, 2007; International Herald Tribune, 2007).

As with other livestock diseases, such as BSE (“mad cow” disease) or Avian Influenza, slight human health risks have had severe impacts on international markets. The possibility of transmission through contact with infected animals has disrupted long-standing trade patterns between the Greater Horn of Africa and the Middle East. Sheep from the Horn of Africa are of a quality that is highly desired for ceremonial slaughter during the Hajj. The slaughter of infected animals is believed to have led to the first outbreak of RVF confirmed outside of Africa (September 2000 in Saudi Arabia). There were large-scale livestock losses and more than one hundred human fatalities (Anyamba and Linthicum, 2006). The resulting ban of livestock imports from Africa by Saudi Arabia led to economic disruption and social unrest for pastoralist communities in the Greater Horn of Africa (FAO-UNDP, 2001). This event, and concern that Rift Valley Fever may become a major international health risk (Madani et al., 2004), has provoked the interest of FAO, WHO, and even the U.S. Department of Defense and NASA.

Testing for the disease is challenging and expensive (Martin et al., 2006). Options for disease prevention are limited. Although vaccines exist, their use is not practical since they are not completely effective, must be applied several months before exposure, only protect sheep for one year, and can have costly side effects.
In addition, they are expensive and challenging to deliver to nomadic pastoralists (FAO-UNDP, 2001).

Among livestock, mosquitoes are the principal disease vector. Since climate affects mosquito populations, there has been hope that rainfall and temperature indicators may predict where and when the disease is likely to occur. Seasonal precipitation and satellite based vegetation indicators can now be predicted with several months of lead time (Indeje, 2006). Researchers have been able to explain eight documented outbreaks between 1950 to 1999 using Pacific and Indian Ocean sea surface temperatures (which are correlated to seasonal precipitation) and normalized difference vegetation indexes calculated from remote-sensing data (Linthicum et al., 1999; Anyamba and Tucker, 2005). In spite of these preliminary steps, much work remains to be done before climate-based RVF forecasts become operational.

RVF causes an unusually high number of sheep abortions, providing a visible indicator for identifying exposed herds (Martin et al., 2006). Fearing future negative repercussions from being labeled RVF positive, individual pastoralists do not come forth to report this information. As an alternative to climate-based forecasts, NGOs and government agencies are beginning to use abortion rates in sentinel herds to identify high-risk areas (Martin et al., 2006).

3 Model

To analyze the effects of repeated interactions between risk-neutral buyer and a fixed number of sellers we develop a model with two periods (where convenient, a subscript \( t = 1, 2 \) denotes the value of a variable in the respective period). Each seller (indexed \( n = 1, \ldots, N \)) has unit supply of a perishable good in each period. A single buyer (with reservation utility of zero) decides the terms under which she will purchase each seller’s good in each period. The buyer cannot commit to a future action that does not maximize her contemporaneous utility. She can use information obtained in period one to design second-period contract terms. The good’s value to the buyer and seller depends on its exogenous quality which can take two values: \( \ell \) (low) or \( h \) (high). Quality is a credence characteristic: it is privately known to the seller, but can only be determined by the buyer by auditing with cost \( \alpha \). The expected values to the buyer of consuming the respective quality of goods are \( v^\ell < 0 < v^h \). For simplicity, we assume that the buyer’s demand is perfectly elastic (for example, the buyer may be an intermediary who resells the goods in a larger market), so that she will by a unit of the good from all sellers for whom the expected value is higher than the cost. The value \( v^\ell \) can be thought of as the expected damage from ultimate consumption of an unsafe good that is internalized.
by the buyer. Note that if a buyer knowingly obtains a low quality good she prefers to discard it rather than allow it to be consumed. The good’s value to the seller is \( c \in \{c^\ell, c^h\} \), where \( 0 = c^\ell < c^h \). We also refer to a seller’s value of \( c \) in a particular period as his current type.

We first focus on market equilibria in the absence of a forecast information system. A seller’s current type is a stochastic function of an underlying state of nature (current local environmental conditions in the RVF example). Without a forecast, the state is not directly observable by the buyer. We assume some intertemporal correlation in the state for each seller. This correlation causes a persistence in type such that the probability that a seller is low quality in period two is higher if he was low quality in period one: i.e., letting \( \rho^i_n = \Pr [c^i_{2n} = c^i | c^i_{1n} = c^i] \) for \( i = \ell, h \), it is the case that \( \rho^\ell_n > \rho^h_n \). Conditional on the state, however, types are assumed to be uncorrelated across time. We denote the unconditional probability that a seller is low quality in any period by \( \rho^u_n \). In general, we express the buyer’s beliefs regarding a seller’s current type as \( \rho^s_n \), where \( s \) is a signal (\( u, \ell, \) or \( h \)) that she can use to update her beliefs. The current expected value to the buyer of a good whose quality becomes known before consumption is thus \( [1 - \rho^s] v^h \), while the expected value of a good whose quality remains hidden is \( [1 - \rho^s] v^h + \rho^s v^\ell \).

The timing of the game between the buyer and sellers is as follows. In period one, nature first randomly assigns a state to each seller and generates his type. Sellers of type \( c^i \) update beliefs regarding their second-period type to \( \rho^i \). The buyer then proposes a single menu of contracts to all sellers (since they are observationally equivalent). Each seller selects a contract setting a probability of audit and payments depending on the outcome of the audit. The resolution of audit uncertainty takes place. Goods and payments change hands if both parties are still willing. The buyer updates her beliefs regarding each seller’s future type. In period two, nature assigns a state to each seller and generates his type. As in the first period, the buyer then proposes a menu of contracts. Unlike period one, the buyer may discriminate among sellers based upon her beliefs regarding the probability that they are low quality. Each seller selects a contract from the menu offered him, audit uncertainty is resolved, and goods and payments change hands.

We model the buyer’s problem as one of assigning contracts to each type of seller in each period, subject to the incentive compatibility constraint that a seller’s assigned contract maximizes his expected utility relative to any other contract on offer to sellers with the same signal. Let \( \tilde{c} \) denote the type to which a contract is assigned, and \( a \) be a variable taking the value \( a^y \) if an audit takes place and \( a^n \) if not. Contract terms to a seller with signal \( s \) consist of a probability of audit \( g^a(\tilde{c}) \), and payments to type \( c \) for choosing
a contract assigned to \( \tilde{c} \) if audited \( p^s (\tilde{c}, c|a^y) \), and if unaudited \( p^s (\tilde{c}, \tilde{c}|a^n) \).

Payments are bounded below by zero (sellers have limited liability), and above by \( \bar{p} > c^b \). The arbitrary upper bound on payments avoids “solutions” involving infinitely large rewards with infinitesimally small audit probabilities (see Border and Sobel, 1987). In practical applications, \( \bar{p} \) could be determined by sellers’ beliefs regarding the buyer’s resources.

In addition to incentive compatibility, we assume contracts satisfy ex post individual rationality with respect to seller participation: sellers can choose not to participate at any time. Let \( q^s (\tilde{c}, c|a) \) be an indicator function that takes a value of unity if a seller of type \( c \) is willing to sell for payment \( p^s (\tilde{c}, c|a) \):

\[
q^s (\tilde{c}, c|a) = \begin{cases} 
0 & \text{if } p^s (\tilde{c}, c|a) < c, \\
1 & \text{otherwise.}
\end{cases}
\]

In period \( t \), a type \( c \) seller’s current expected profit from choosing a contract assigned to \( \tilde{c} \) is \( \pi^s_t (\tilde{c}, c) \), where

\[
\pi^s_t (\tilde{c}, c) = g^s_t (\tilde{c}) q^s_t (\tilde{c}, c|a^y) [p^s_t (\tilde{c}, c|a^y) - c] \\
+ [1 - g^s_t (\tilde{c})] q^s_t (\tilde{c}, c|a^n) [p^s_t (\tilde{c}, c|a^n) - c].
\]

As a notational convention, \( P^s_t (c|a) \equiv p^s_t (c, c|a) \), \( Q^s_t (c|a) \equiv q^s_t (c, c|a) \), and \( \Pi^s_t (c|a) \equiv \pi^s_t (c, c|a) \).

A seller’s total expected profit over both periods, conditional on his first-period contract choice is \( \pi^s_1 (\tilde{c}, c) \) plus expected second-period profit conditional on how he believes the buyer will react to his first-period contract choice. In calculating utility we implicitly assume all parties do not discount future income. Relaxing this assumption would complicate the notation without adding significant new insights.

The buyer’s current utility from a proposed contract menu is her expected net benefit: expected value of purchased good less expected payment and expected audit cost. The buyer’s total expected utility over both periods conditional on her first-period contract menu is her first-period expected net benefit plus expected second-period net benefits conditional on information revealed by sellers in their first-period contract choice.

We use the concept of Perfect Bayesian Equilibrium (PBE) to model the game between the buyer and the seller (see, for example, Freixas et al., 1985). A set of payoffs is a PBE if it can be implemented by a set of strategies and beliefs for which:

i. Each seller’s second-period contract assignment maximizes his expected utility among the set of avail-
able contracts;

ii. The second-period contract menu maximizes the buyer’s expected utility given her beliefs regarding the distribution of types and condition i above;

iii. Each seller’s first-period contract assignment maximizes his expected utility among the set of available contracts given his beliefs regarding how this contract affects the buyer’s beliefs and, consequently, the second period contract design via ii above;

iv. The first-period contract menu maximizes the buyer’s expected utility given her beliefs regarding the distribution of types and condition iii above;


We identify each potential PBE through backwards induction. First we identify equilibria for the second-period sub-game, i.e., contracts that satisfy points i and ii in period two for all possible first-period outcomes. We then use these results to identify equilibria for the first-period contracts that satisfy points iii and iv. Equilibria can be characterized by separation or pooling. If an equilibrium exhibits separation in a given period, it is optimal for the buyer to allocate a different contract to each type of seller in that period (and for each type of seller to choose the contract intended for him). As a result, in a period with separation the buyer updates her beliefs regarding each seller’s type after he chooses a contract. In a period with pooling, it is optimal for the buyer to assign an identical contract to all types. As a result, the buyer does not gain any information from contract choice with which to update her beliefs. In such a case, the buyer can only update her beliefs for an individual seller if an audit occurs. In each period we analyze how the availability of a forecast affects the set of possible equilibria.

4 Market equilibria without a forecast

In this section we derive the PBE of the game between the buyer and sellers for cases in which a forecast information system is unavailable. We first derive equilibria for the second-period subgame, then use these results to identify equilibria for the entire game.
4.1 Period Two

In period two, the buyer’s signal is either $\ell$ or $h$ if she knows the seller’s first-period type, or $u$ if she does not. Additionally, as there are no further interactions, each seller knows that his current contract choice only affects current payoffs.

By equilibrium condition $i$, each type of seller must maximize utility by choosing his assigned contract. For the sellers, utility is expected profit, given the probabilities of audit and payout schemes of the offered contracts. This incentive compatibility (IC) constraint is

\[ (3) \quad \Pi_s^x(c) \geq \pi_s^x(\check{c}, c) \quad \text{for all} \quad (\check{c}, c). \]

If this condition is satisfied, a seller’s pure strategy of choosing his assigned contract is dominated neither by choosing a different contract nor pursuing a mixed strategy of randomizing contract choice.

The buyer’s problem is to choose contract terms for each signal to maximize expected profits subject to IC:

\[ \max_{g_s^x(c), P_s^x(c|a)} \left[ 1 - \rho^x \right] \left[ g_s^x(c^h) \left[ Q_s^x(c^h|a^y) \left[ \pi_s^x(c^h) - P_s^x(c^h|a^y) \right] - \alpha \right] + \right. \]

\[ \left. \left[ 1 - g_s^x(c^h) \right] Q_s^x(c^h|a^u) \left[ \pi_s^x(c^h) - P_s^x(c^h|a^u) \right] \right] - \rho^x \left[ g_s^x(c^l) \left[ P_s^x(c^l|a^y) + \alpha \right] + \left( 1 - g_s^x(c^l) \right) P_s^x(c^l|a^u) \right]. \]

IC constraint (3) can be simplified by recognizing that the payment to an audited seller caught choosing the “wrong” contract should be as low as possible, i.e., zero. Doing so reduces $\pi_s^x(\check{c}, c)$ for $\check{c} \neq c$, thus making it easier to satisfy constraint (3). It does not adversely affect the buyer’s welfare or affect participation constraints, since in equilibrium sellers choose the contract assigned to them. Constraint (3) can then be restated as

\[ (5) \quad \Pi_s^x(c^l) \geq \left[ 1 - g_s^x(c^l) \right] q_s^x(c^l, c^l|a^u) \left[ P_s^x(c^l|a^u) - c^l \right], \]

for $i, j = \ell, h; \ i \neq j$.

As shown in Lemma 1, constraint (5) only binds for type $c^l$. As a result, it is not optimal for the buyer
to audit \(c^f\) declarations. It is optimal for her to set the price paid to \(c^h\) declarations (either audited or unaudited) to either zero (if it is not worthwhile to purchase) or to the minimum necessary to induce type \(c^h\) to sell. It is also optimal for her to set the price paid to an unaudited \(c^f\) contract equal to the expected payment that would be received by a type \(c^f\) choosing a contract assigned to type \(c^h\).

**Lemma 1** In equilibrium,

\[
\begin{align*}
g^2_s (c^f) &= 0, \\
P^a_2 (c^h|a^y), P^a_2 (c^h|a^n) &\in \{0, c^h\}, \text{ and} \\
P^a_2 (c^f|a^n) &= [1 - g^a_2 (c^h)] P^a_2 (c^h|a^n). 
\end{align*}
\]

Lemma 1 allows us to simplify the buyer’s second-period problem to

\[
\max_{g^2_s (c^h), P^a_2 (c^h|a)} [1 - \rho^s] \left[ g^2_s (c^h) \left[ Q^a_2 (c^h|a^y) \left[ v^h - P^a_2 (c^h|a^y) \right] - \alpha \right] + \\
[1 - g^a_2 (c^h)] Q^a_2 (c^h|a^n) \left[ v^h - P^a_2 (c^h|a^n) \right] \\
- \rho^s \left[ 1 - g^a_2 (c^h) \right] P^a_2 (c^h|a^n) \right].
\]

(6)

Let \(\hat{U}^a_2\) denote the solution to (6). The following proposition identifies the three possible equilibrium values of \(\hat{U}^a_2\). Which of the three outcomes is the equilibrium depends upon the relative values of \(\rho^s, v^h, \alpha,\) and \(c^h\).

**Proposition 1** In period two, for sellers with signal \(s\), the buyer’s equilibrium utility is the maximum of i) \([1 - \rho^s] v^h - c^h\); ii) \([1 - \rho^s] [v^h - c^h - \alpha]\); or iii) 0.

Second-period contracts take one of three simple forms. Since the marginal cost of audit is assumed to be constant, the buyer’s objective function is linear in \(g^a_2 (c^h)\). Therefore a corner solution arises in which it is optimal to use a deterministic auditing strategy for sellers who choose type \(c^h\) contracts. If no audits are conducted, then Lemma 1 requires that both contracts provide the same payment. In such a case, if the buyer decides to purchase she must offer \(c^h\) to all sellers obtaining an expected utility of \([1 - \rho^s] v^h - c^h\) per seller with signal \(s\). If the buyer increases the probability of auditing type \(c^h\) contracts, she incurs an expected marginal cost equal to the audit cost multiplied by the probability of encountering a type \(c^h\) seller, \(\alpha [1 - \rho^s]\). In exchange, she gains an expected benefit equal to the expected marginal reduction in payments.
to type $c^e$ sellers, $c^h\rho^s$. Since neither of these terms depends upon $g_2^*(c^h)$, the buyer should increase the audit probability to one if

$$
(7) \quad \alpha [1 - \rho^s] < c^h\rho^s,
$$

and reduce it to zero otherwise. If the buyer audits with probability one then Lemma 1 indicates that $P_2^*(c^h|a^n) = c^h$, and $P_2^*(c^e|a^n) = 0$. In such a case the buyer obtains an expected utility of $[1 - \rho^s] [v^h - c^h - \alpha]$ per seller with signal $s$.

With some algebraic manipulation, we restate condition (7) for full auditing of $c^h$ contracts as

$$
(8) \quad [1 - \rho^s] [v^h - c^h - \alpha] > [1 - \rho^s] v^h - c^h.
$$

The two sides of this inequality are the values of the buyer’s objective function if she always audits (left-hand side) or never audits (right-hand side) sellers choosing contracts assigned to type $c^h$, supposing that she always purchases from type $c^h$. Thus, the buyer purchases from type $c^h$ if and only if one of these two values is greater than zero. Otherwise, the best she can do is not enter the market, obtaining zero expected utility per seller with signal $s$.

Which contract menu is optimal for the buyer depends on two sets of relationships among the exogenous variables. If the buyer’s net value from obtaining an audited high-quality good is negative ($v^h - c^h - \alpha < 0$) then it is never optimal to audit, regardless of the value of any other variable. In such a case, the buyer pays all sellers $c^h$ if $\rho^s < (v^h - c^h) / v^h$, otherwise the market collapses.

If, however, $v^h - c^h - \alpha > 0$ the market does not collapse. Again, the optimal contract depends on the buyer’s belief regarding the probability of encountering a low-quality good. If $\rho^s < \alpha / (c^h + \alpha)$ the probability is low enough that it is optimal to pay all sellers $c^h$. Otherwise, it is optimal to audit and pay only sellers who choose the contract assigned to type $c^h$.

Note that type $c^e$ sellers never receive positive profit. They either receive a payment exactly equal to their opportunity cost or receive nothing. Type $c^e$ sellers can receive profit, but only if $\rho^s$ is sufficiently low. If $v - c^h - \alpha < 0$ and $\rho^s > (v^h - c^h) / v^h$, then they receive nothing (because the market collapses). Likewise, if $v^h - c^h - \alpha > 0$ and $\rho^s > \alpha / (c^h + \alpha)$, they also receive nothing (because the buyer audits all $c^h$ contracts). The only equilibrium in which type $c^e$ sellers receive profit is the one in which all contracts pay $c^h$ with no
auditing.

Although the market can collapse if the probability of encountering a low-quality good is sufficiently high, in none of the three equilibria does the market break down due to the damage from unknowingly purchasing a low-quality good. In other words, in each equilibrium the buyer can accurately infer each seller’s type from his choice of contracts.\textsuperscript{14}

The actual response of livestock markets to RVF does not appear to resemble any of these outcomes. Comprehensive tests of animal health are not typically undertaken (which may be explained by their high cost). Although actual payments are not differentiated by health status, sellers do not report their type. As a consequence, sick animals occasionally are unknowingly purchased resulting in human illness, risks of boycotts, etc. To understand why actual markets are not characterized by disclosure, it is necessary to extend the analysis back to period one.

To streamline the analysis, we now impose two assumptions on relative parameter values.

**Assumption 1** \(v^h - c^h - \alpha < 0\).

**Assumption 2** \(\rho^\ell > \hat{\rho} > \rho^u > \rho^h\), where \(\hat{\rho} \equiv (v^h - c^h) / v^h\).

The first assumption ensures that it is not optimal for the buyer to audit in period two regardless of the value of \(s\). This assumption avoids trivial solutions in which the buyer uses a “brute force” method of overcoming the information asymmetry by auditing all healthy types. For the second assumption, \(\hat{\rho}\) is the cut-off probability such that the buyer is willing to purchase only from sellers with \(\rho^s < \hat{\rho}\). This assumption ensures that information provided by a seller’s past history is non-trivial, i.e., the buyer would like to offer different contracts to sellers depending on \(c_1\). In other words, expected profit from sellers with \(h\) and \(u\) signals is positive, while expected profit from sellers with \(\ell\) signals is negative. Under these assumptions, second-period equilibrium buyer expected utility conditional on the signal is

\[
\hat{U}_2^s = \begin{cases} 
[1 - \rho^s] v^h - c^h & \text{for } s = h, u; \\
0 & \text{for } s = \ell.
\end{cases}
\]

**4.2 Period One**

Since the buyer is unable to commit to a second-period strategy that is against her interest at that time, each seller assumes that she will use first-period contract choices to update beliefs for period two. By
affecting the buyer’s beliefs, this signal can potentially affect the seller’s second-period welfare by influencing the equilibrium contract menu.

In a separating equilibrium, each type of seller chooses a different contract. It is rational for the buyer to believe that contract choice reveals sellers’ true types. For a first-period separating equilibrium, a seller’s expected second-period profit conditional on first-period type and contract choice is

\[
E_{c_2} \left[ \Pi_2 (c_2) | c_1 = c^i, \tilde{c}_1 = c^j \right] = \begin{cases} 
\rho^i c^h & \text{if } \rho^j < \hat{\rho}, \\
0 & \text{otherwise},
\end{cases}
\]

for \( i, j \in \{ \ell, h \} \).

Expected second-period profit is weakly decreasing in \( \rho^s \). Regardless of a seller’s true type, by choosing a contract assigned to type \( c^h \) in the first period, the seller cannot reduce his expected second-period profit.

Assumption 2 ensures that in a separating equilibrium low-type sellers in period one face a stronger incentive compatibility constraint than in period two. In addition to being compensated for first-period consequences of revealing their type, they must also be compensated for the reduction in second-period expected profit of \( \rho^j c^h \). This future cost is equal to the probability that the seller is type \( c^\ell \) the next period multiplied by the loss in future profit if there is no transaction.

Since there is no previous period, the signal in period one is \( u \) for all sellers. As in period two, for a separating equilibrium the IC constraint can be simplified by recognizing that the current payment to an audited seller choosing the “wrong” contract is optimally zero. First-period IC then requires

\[
\Pi_1^n (c^j) \geq \left[ 1 - g^n_1 (c^j) \right] \left[ q^n_1 (c^j, c^j | a^n) \left( P_1^n (c^j | a^n) - c^j \right) + \rho^j [c^j - c^j] \right]
\]

for \( i, j \in \{ \ell, h \} ; i \neq j \).

In a pooling equilibrium, the buyer assigns the same contract to both types and thus cannot use contract choice to update her beliefs. The notation \( c^0 \) indicates that there is only one type of contract. The terms of a pooling contract are \( \langle g^n_1 (c^0), p_1^n (c^0, c^\ell | a^y), P_1^n (c^0 | a^n), p_1^n (c^0, c^h | a^y) \rangle \). Since both types react the same way in a pooling equilibrium, the buyer sets either \( P_1^n (c^0 | a^n) = c^h \), in which case she purchases from both types, or \( P_1^n (c^0 | a^n) = 0 \) in which case she does not purchase from any type. Also, the buyer sets \( p_1^n (c^0, c^\ell | a^y) = 0 \) since any higher price only increases the her expenditure without any increase in her welfare. Similarly,
$p^u_1(c^0, c^h | a^u) = c^h$, since no higher price is necessary to induce a type $c^h$ to sell, and at any lower price the buyer would forfeit gains of $v^h - c^h$. The best the buyer can do in a first-period pooling equilibrium is thus to choose the maximum of

\[
\max \frac{a^*_1(c^0)}{p^u_1(c^0)} \left\{ [1 - \rho^u] \left[ v^h - c^h + g^u_1(c^0) \left[ \hat{U}_2^h - \alpha \right] + [1 - g^u_1(c^0)] \hat{U}_2^u \right] - \rho^u g^u_1(c^0) \left[ \alpha - \hat{U}_2^h \right] + [1 - g^u_1(c^0)] \left[ c^h + v^\ell - \hat{U}_2^u \right] \right\},
\]

or

\[
\max \frac{a^*_1(c^0)}{p^u_1(c^0)} \left\{ [1 - \rho^u] \left[ g^u_1(c^0) \left[ v^h - c^h + \alpha + \hat{U}_2^h \right] + [1 - g^u_1(c^0)] \hat{U}_2^u \right] - \rho^u g^u_1(c^0) \left[ \alpha - \hat{U}_2^h \right] - [1 - g^u_1(c^0)] \hat{U}_2^u \right\}.
\]

Here, the first expression corresponds to total expected utility in both periods if $P^u_1(c^0 | a^u) = c^h$ and the second corresponds to total utility if $P^u_1(c^0 | a^u) = 0$.

The buyer’s maximized expected utility over both periods is denoted $\hat{U}$. The following proposition identifies the six possible equilibrium values of $\hat{U}$. Which of these prevails depends upon the relative values of $\rho^u$, $\rho^\ell$, $\rho^h$, $v^h$, $v^\ell$, $\alpha$, $c^h$, and $\bar{p}$.

**Proposition 2** The buyer’s expected equilibrium utility over both periods, $\hat{U}$, is the maximum of:

1. $\hat{U}_2^u$;
2. $\hat{U}_2^u + [1 - \rho^u] v^h - c^h + \rho^u v^\ell$;
3. $[1 - \rho^u] \left[ \hat{U}_2^h + v^h - c^h - \alpha \right]$;
4. $[1 - \rho^u] \left[ \hat{U}_2^h + v^h \right] - c^h \left[ 1 + \rho^u \rho^\ell \right] + \frac{\rho^\ell - \rho^h}{1 + \rho^h} \rho^u c^h \left[ 1 + \rho^\ell \right] - [1 - \rho^u] \alpha$;
5. $[1 - \rho^u] \left[ \hat{U}_2^h + v^h - c^h \left[ \rho^\ell - \rho^h \right] \right] - c^h \left[ 1 + \rho^u \rho^\ell \right] + \frac{\rho^\ell - \rho^h}{\rho^h + \rho^\ell} \rho^u c^h \left[ 1 + \rho^\ell \right] - [1 - \rho^u] \alpha$;
6. $[1 - \rho^u] \left[ \hat{U}_2^h + v^h \right] - c^h \left[ 1 + \rho^u \rho^\ell \right] - \frac{c^h \left[ 1 + \rho^\ell \right]}{\bar{p}} \rho^u \alpha$.

The first two potential equilibria exhibit pooling. As a result, the buyer cannot update her beliefs and second-period expected utility is $\hat{U}_2^u$ per seller. The simplest of these is equilibrium 1 in which the buyer does not purchase from anyone. In this equilibrium, first-period utility is zero for the buyer and all sellers. In the second pooling equilibrium, the buyer offers all sellers a payment equal to $c^h$. In this equilibrium alone do undisclosed low-quality goods enter the market.
The next three potential equilibria are separating, and involve zero probability of audit for type $c^s$ sellers. These equilibria differ by the probability of auditing type $c^h$ contracts, the payments to low types, and the payments to audited high types. Essentially, there is a trade-off between probability of audit and the expected payment necessary to induce $c^s$ sellers to choose the contract assigned to them: the higher the chance of being caught choosing the wrong contract, the lower the payment. If the audit probability is sufficiently high, there is no such trade-off for high types. In such a case, the premium offered to low types is not large enough to offset the expected loss in future rents incurred by a high type claiming to be a low type. A payment of $c^h$ is then sufficient to induce high types to choose their assigned contract. If the audit probability is low enough, however, the corresponding payment to low types is sufficiently high that audited type $c^h$ sellers “caught” choosing their assigned contract must receive a reward in order to dissuade them from claiming to be low types. The expected value of the reward is constant: the larger the reward, the lower the audit probability necessary to induce them to choose the assigned contract. Since auditing is costly, it is optimal for the buyer to make the reward as large as possible, i.e., $\bar{p}$.

Which of these three choices gives the buyer the highest utility depends upon the net marginal benefit of increasing the probability of auditing type $c^h$ contracts. Similar to period two, the expected marginal cost of increasing $g^u_1(c^h)$ is $[1 - \rho^u] \alpha$. The expected marginal benefit is higher in this period, however, since the low type seller must be compensated for both foregone payments in period one ($c^h$) and expected foregone payments in period two ($\rho c^c$) from revealing his type. Thus, the expected reduction in payments to low types obtained by increasing the audit probability is $\rho^u c^h [1 + \rho^s]$. If $[1 - \rho^u] \alpha \leq \rho^u c^h [1 + \rho^s]$ then the optimal value of $g^u_1(c^h)$ for the buyer (within the set of options 3, 4, and 5) is unity, i.e., option 3. In addition, this condition is sufficient to ensure that option 3 also dominates option 6. If $g^u_1(c^h) > \frac{\rho^u - \rho^h}{1 + \rho^s}$, then the payments necessary to induce a low types to choose his assigned contract is sufficiently low that there is no temptation for high types to mimic low types when offered a payment equal to his opportunity cost $c^h$. If $g^u_1(c^h) < \frac{\rho^u - \rho^h}{1 + \rho^s}$, however, type $c^s$ contracts become attractive to high types. As a result, it is necessary to increase the expected payment to type $c^h$ for choosing the assigned contract. The marginal benefit for the buyer of increasing $g^u_1(c^h)$ if it is below $\frac{\rho^u - \rho^h}{1 + \rho^s}$ is $c^h [1 + \rho^s]$: the reduction in expected payments to low types, $\rho^u c^h [1 + \rho^s]$, plus the reduction in expected payments to high types, $[1 - \rho^u] c^h [1 + \rho^s]$. Therefore, if $\rho^u c^h [1 + \rho^s] \leq [1 - \rho^u] \alpha < c^h [1 + \rho^s]$ then the optimal value of $g^u_1(c^h)$ (again, within the set of options 3, 4, and 5) is $\frac{\rho^u - \rho^h}{1 + \rho^s}$ (option 4). If $[1 - \rho^u] \alpha > c^h [1 + \rho^s]$, then the cost of audit is so high that the buyer...
would like to reduce it as far as possible. To preserve incentive compatibility, $g^u_i (c^h)$ can only be reduced if there is a corresponding increase in $P^u_i (c^h|a^y)$. Since for options 3 through 5 $g^u_i (c^f) = 0$, the lowest value of $g^u_i (c^h)$ consistent with a separating equilibrium is $\frac{c^h [\rho^f - \rho^h]}{\rho^f + \rho^h}$. In this case, option 5 dominates options 3 and 4. Once the buyer determines the best option out of 3, 4, and 5, she can compare it to the best of options 1, 2, and 6 to identify the global maximum, and her equilibrium utility.

Option 6 involves random auditing of type $c^f$ contracts, and no audits of type $c^h$ contracts. Auditing low types with strictly positive probability allows the buyer to remove any temptation for high types to choose a type $c^f$ contract. Intuitively, the buyer can offer unaudited type $c^f$ contracts a payment of zero, and give audited type $c^f$ sellers a large enough reward such that its expected value is sufficient to induce them to choose the type $c^f$ contract. Since the unaudited payment is zero, there high types have no incentive to choose this contract. Any positive audit probability is sufficient to achieve this effect. Smaller audit probabilities simply require a higher reward to maintain the same expected payout. Since audits are costly, it is in the buyer’s interest to keep $g^u_i (c^f)$ as low as possible. The expected payout for a low type is optimally that his expected foregone income, $c^h [1 + \rho^f]$. The maximum reward $\bar{p}$ determines the minimum level of $g^u_i (c^f)$, i.e., $g^u_i (c^f) \bar{p} = c^h [1 + \rho^f]$. Whether option 6 outperforms the other possible equilibria depends upon the probability of encountering a type $c^f$ seller and the maximum reward. All else equal, option 6 becomes more attractive as $\rho^u$ decreases and $\bar{p}$ increases.

5 Market equilibria with a forecast

In this section, we show how introduction of a forecast device changes equilibrium outcomes in each period. We identify welfare effects on buyer and sellers from introducing a forecast as well as increasing forecast precision. We model a forecast information system as an instrument that identifies the second period state of nature for each seller, and uses this information to generate a probability $\rho^\phi$ that a seller is a low type in period two. Let $f^{\phi|c_1} (\rho^\phi|c)$ denote the probability density function of $\rho^\phi$ conditional upon that seller’s type in period one. Also, let $f^\phi (\rho^\phi)$ denote the marginal density of $\rho^\phi$, and $F^\phi (\rho^\phi)$ and $F^{\phi|c_1} (\rho^\phi|c)$ denote the corresponding distribution functions. In the absence of a forecast, the probability that $c_2 = c^f$ is thus $\rho^f = \int_0^1 \rho f^{\phi|c_1} (\rho|c^f) \, d\rho$, $i \in \{f, h\}$. The unconditional probability that a seller (in any period) is type $c^f$ is $\rho^u = \int_0^1 \rho f^\phi (\rho) \, d\rho$. Since, conditional on knowing the state, we assumed no correlation between $c_{1n}$ and $c_{2n}$, knowledge of $c_{1n}$ provides no additional information regarding a seller’s type once a forecast has been
5.1 Period Two

If a forecast is available, the buyer’s signal in period two is $\phi$, rather than $\ell$, $h$, or $u$. (In the absence of a forecast, the signals $\ell$, $h$, or $u$ effectively serve as proxies for $\phi$.) As such, the buyer cannot be made worse off by having access to the improved information provided by the forecast. The actual second-period value to the buyer of the forecast information relative to the signals provided by her beliefs regarding sellers’ first-period types depends upon how she can use this information to improve her ex ante decision making.

The fundamental way that a forecast helps the buyer is by allowing her to discriminate between sellers that otherwise would have been observationally equivalent. Specifically, the forecast is valuable inasmuch as it gives her the opportunity to purchase from low-risk sellers that she otherwise would have avoided (due to an $\ell$ signal, for example) and avoid high-risk sellers from whom she otherwise would have purchased (due to an $h$ signal). Optimally, the buyer only transacts with sellers for whom she receives a signal $\rho^\phi < \hat{\rho}$. Her expected second period utility is thus $E [u^b [1 - \rho^\phi] - c^h | \rho^\phi < \hat{\rho}] F^\phi (\hat{\rho})$. As shown in the following lemma, a forecast unambiguously helps the buyer in period two.

**Lemma 2** The buyer’s expected utility is higher in period two with a forecast than without.

The forecast’s second-period welfare effects on the buyer are similar to results in the literature on production under uncertainty. From the buyer’s perspective the forecast provides value only to the extent to which it enables her to improve her ex ante decision-making. In this sense it is analogous to results Mjelde et al. (1993) and Costello et al. (1998) for U.S. corn and salmon producers respectively or Luseno et al. (2003) in the context of precipitation forecasts for African pastoralists.

Unlike the buyer, in period two sellers can either gain or lose ex ante from the availability of a forecast. Consider a first-period separating equilibrium. Sellers who are type $c^\ell$ in period one experience an unambiguous gain in expected second-period welfare from the introduction of a forecast. Without the forecast, they would have received zero profit in period two. With a forecast, there is a chance that they will receive a signal such that $\rho^\phi < \hat{\rho}$ and be type $c^\ell$ in period two. In such a case they receive positive profit. Sellers who are type $c^h$ in period one experience an unambiguous loss from the forecasting device. Without a forecast, the buyer would have contracted with all these sellers. With a forecast, the buyer refuses to pay any seller who receives a signal $\rho^\phi > \hat{\rho}$. The expected profit loss from a forecast is then equal to $c^h$ times
the probability that these sellers receive a signal above \( \hat{\rho} \) and are type \( c^\ell \) in the second period. Before a seller knows \( c_1 \), which of these effects dominates depends on the probability of being type \( c^\ell \). For a first period pooling equilibrium, the welfare impact for all sellers is the same as that for type \( c^h \) in the separating equilibrium (since we assume the buyer transacts with sellers having a \( u \) signal in period two). These results are summarized in the following lemma.

**Lemma 3** In period two, after a first-period separating equilibrium a seller for whom \( c_1 = c^\ell \) benefits, and a seller for whom \( c_1 = c^h \) suffers from the introduction of a forecast. Ex ante, sellers can either gain or lose from a forecast depending on \( \rho^u \). After a pooling equilibrium sellers unambiguously suffer from introduction of a forecast.

To evaluate the effect of forecast precision, we must first develop an economically relevant definition of what it means to be “precise.” We define a forecast information system \( \varphi \) as being more precise than \( \phi \) if it has the same conditional expectations (i.e., \( \int \rho f^\varphi \omega \left( \rho\mid c^i \right) d\rho = \rho^i, i \in \{\ell, h\} \), and \( \int \rho f^\varphi \left( \rho \right) d\rho = \rho^u \) and it yields no lower second-period utility to the buyer regardless of the values of \( v^h \) and \( c^h \). Lemma 4, shows that these requirements imply that the distribution of \( f^\varphi \left( \rho^\varphi \right) \) is a mean-preserving spread of \( f^\phi \left( \rho^\phi \right) \). Intuitively, the buyer prefers forecasts that generate a distribution of probabilities that is thick in the tails (ideally \( \rho^u \) zeros and \( (1 - \rho^u) \) ones). A useless forecast would generate an identical probability, \( \rho^u \), for all sellers.

**Lemma 4** If \( f^\varphi \left( \rho^\varphi \right) \) and \( f^\phi \left( \rho^\phi \right) \) have the same mean and the buyer prefers forecast \( \varphi \) to forecast \( \phi \), for all \( v^h \) and \( c^h \) then \( f^\phi \left( \rho^\phi \right) \) second-order stochastically dominates \( f^\varphi \left( \rho^\varphi \right) \).

Although sellers may gain from the introduction of a forecasting device (if \( \rho^u \) is sufficiently high), the following proposition shows that in period two an increase in forecast precision: i) hurts the average seller; and ii) results in a net collective welfare gain.

**Proposition 3** Suppose \( \varphi \) is more precise than \( \phi \). Then,

i. \( E_{c_1} \left[ E_{\rho^\varphi} \left[ E_{c_2} \left[ \Pi_2^\varphi \left( c_2 \mid \rho^\varphi \right) \left| c_1 \right| \right] \right] \right] > E_{c_1} \left[ E_{\rho^\phi} \left[ E_{c_2} \left[ \Pi_2^\phi \left( c_2 \mid \rho^\phi \right) \left| c_1 \right| \right] \right] \right] \); and

ii. \( E_{c_1} \left[ E_{\rho^\varphi} \left[ E_{c_2} \left[ \Pi_2^\varphi \left( c_2 \mid \rho^\varphi \right) \left| c_1 \right| \right] \right] \right] + E \left[ v^h \left[ 1 - \rho^\phi \right] - c^h \mid \rho^\phi < \hat{\rho} \right] F^\phi \left( \hat{\rho} \right) < E_{c_1} \left[ E_{c_2} \left[ \Pi_2^\phi \left( c_2 \mid \rho^\phi \right) \left| c_1 \right| \right] \right] + E \left[ v^h \left[ 1 - \rho^\varphi \right] - c^h \mid \rho^\varphi < \hat{\rho} \right] F^\varphi \left( \hat{\rho} \right). \)
These results differ substantially from other research on welfare impacts of forecasts (e.g., Pfaff et al., 1999; Broad et al., 2002). This earlier qualitative analysis developed intuition how introducing a forecast might help some segments of society while hurting others. Their results depended, however, on differences in access to forecast information, rather than a commonly observed signal. Specifically, for the case of Peruvian fisheries, due to their superior access to and understanding of climate forecasts, provision of this information may help industrial fishing companies at the expense of labor unions and artisanal fishers. Proposition 3 indicates formally how improvements in precision can have opposing welfare effects on different segments of society, even if access and understanding is identical. Although exogenous improvements in precision necessarily help society as a whole, failure to compensate the losers may result in political opposition to introduction of forecasts. The magnitude of the second-period welfare impacts of a forecast device are directly related to its precision.

5.2 Period One

In the previous section, we saw that the availability of a forecast in period two can cause the buyer to modify the characteristics of her proposed contract menu relative to the no-forecast equilibrium. Specifically, the forecast could lead her to purchase from some sellers that she otherwise would have avoided, and to avoid some sellers from whom she otherwise would have purchased. Introduction of a forecast may or may not improve the welfare of sellers, but once a forecast is introduced any further improvements in forecast skill unambiguously hurt seller welfare while improving buyer welfare.

Although the information provided by the forecast only becomes available in period two, it can have dramatic effects on first-period equilibrium contracts as well. Specifically, if a forecast is available, then the buyer’s beliefs regarding the probability that a seller has a low-quality good in period two no longer depend upon the seller’s first-period actions. Thus, the forecast plays the role of a mechanism by which the buyer can credibly commit to ignore sellers’ first period contract choice.

Since with a forecast there are no future repercussions from disclosing low quality, sellers’ first-period incentive compatibility constraints are identical to those in period two. As a result, there is no pooling equilibrium in which low-quality goods are not disclosed. Also, there are no equilibria with random audits. Thus the availability of a forecast can have two major effects on first-period contracting relative to the no-forecast scenario.
First, consider the case of a no-forecast separating equilibrium. The availability of a forecast means that a complicated mechanism involving random audits and high rewards for audited sellers is replaced by a simple mechanism of paying every seller the same price. In addition, in order for a separating equilibrium to hold, sellers must believe that the buyer is truthfully reporting the audit probability when they know that she has an incentive to overstate it. In practice, sellers may not be able to distinguish precisely between different audit probabilities.

A second consideration arises with respect to the buyer’s credibility to commit to actions that are not in her immediate self-interest. Specifically, in the no-forecast separating equilibria 4, 5, and 6, the buyer audits infrequently and gives high rewards to audited sellers. In a separating equilibrium, however, sellers effectively identify themselves by choice of contract. In a larger sense, therefore, it has to be credible for the seller to commit to undertake costly audits even though she can already identify sellers’ types by their contract choice. As discussed by Khalil (1997) and Chen and Liu (2005), the buyer may no longer be able to perfectly separate sellers by type if such credibility is lacking. Without commitment, the equilibrium may involve mixed strategies wherein sellers randomize between lying and truth-telling. Due to these factors, first-period separating equilibria may not be viable in practice, and the buyer can expect to unknowingly purchase low-quality goods. Availability of a forecast simplifies matters by eliminating the necessity of random audits to induce disclosure.

Next, consider the case of a no-forecast pooling equilibrium. In this case, the forecast can have two types of impact. First, if the pooling equilibrium was one of market collapse, the forecast can allow for purchasing. To see this, note from Proposition 2 that without a forecast a market collapse (equilibrium number 1) always occurs if \( (1 - \rho^u) v^h - c^h < 0 \), but may also occur if \( (1 - \rho^u) v^h - c^h > 0 \). With a forecast, however, Proposition 1 indicates that a market collapse only occurs if \( (1 - \rho^u) v^h - c^h < 0 \). Second, if the pooling equilibrium was one of purchasing from all, then the availability of a forecast eliminates the possibility undisclosed low-quality goods entering the market.

This result is worth emphasizing. Even an imprecise forecast in period two can result in perfect detection of low-quality goods in both periods. It does this by enabling the buyer to give incentives to each seller to voluntarily disclose quality. As a result, no damage is incurred by undisclosed low-quality goods.

We can now evaluate welfare effects on the buyer and sellers of introducing a forecast. First, note that a forecast can only increase total buyer welfare over both periods. The first-period impact of a forecast
is to sever the link between sellers’ first-period contract choice and second-period utility. Once the link is severed, increases in precision have no further effect on first-period equilibrium contracts. Thus, precision does not affect equilibrium expected buyer utility in period one.

The table below indicates a seller’s ex ante first-period profit associated each of the possible no-forecast equilibria.

Table 1: Expected First-Period Seller Welfare without Forecast

<table>
<thead>
<tr>
<th>No-forecast equilibrium</th>
<th>Expected first-period seller welfare</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>$\rho^u c^h$</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>$\rho^u [1 + \rho^h] c^h$</td>
</tr>
<tr>
<td>5</td>
<td>$\rho^u \frac{\bar{\theta} + c^h \rho^u}{\rho^u + c^h \rho^u} c^h \left[ 1 + \rho^f \right] + \left[ 1 - \rho^u \right] \left[ \frac{c^h \left[ \rho^f - \rho^h \right] - \rho^u c^h}{\rho^u + c^h \rho^u} \right] \left[ - c^h \right]$</td>
</tr>
<tr>
<td>6</td>
<td>$\rho^u c^h \left[ 1 + \rho^f \right]$</td>
</tr>
</tbody>
</table>

As in period two, a seller’s expected first-period utility can either increase or decrease with the introduction of a forecast. With a forecast, a seller’s expected first-period utility is zero if there is no transaction. Otherwise, a seller’s expected utility is $\rho^u c^h$. If the no-forecast equilibrium is characterized by random audits (4, 5, or 6) a seller’s expected first-period utility is necessarily lowered by introducing a forecast device. Conversely, if the no-forecast equilibrium is either 1 or 3, a seller’s expected first-period utility cannot be lowered (and may be raised) by introducing a forecast device. For example, if in a no-forecast equilibrium results in no transactions, then a seller’s expected first-period utility increases from zero to $\rho^u c^h$ with the introduction of a forecast. In other words, without a forecast the buyer does not enter the market in period one if the audit cost and damage from unknowingly purchasing a low-quality good are sufficiently high. With a forecast, however, the buyer would be willing to pay $c^h$ to all sellers in exchange for truthful disclosure (since $\rho^u < \hat{\rho}$). Such revelation would be an equilibrium since the forecast effectively disconnects the sellers’ future contract from the buyer’s beliefs regarding current type.

If 2 is the no-forecast equilibrium then a forecast does not affect sellers’ first-period expected utility. To see this, note that for 2 to be the equilibrium, it must be the case that $[1 - \rho^u] v^h - c^h + \rho^u v^f > 0$ (else 2 would be dominated by 1) and that $[1 - \rho^u] \alpha > \rho^u \left[ c^h - v^f \right] + \left[ 1 - \rho^u \right] \left[ \bar{U}_2 - \bar{U}_2^u \right] > \rho^u c^h$ (else 3 would be the equilibrium). With a forecast, the sellers’ expected utility (under our working assumptions
\[ (1 - \rho^n) \nu^h - c^h > 0 \text{ and } (1 - \rho^n) \alpha > \rho^n c^h \] is \( \rho^n c^h \), the same as without a forecast. This last result is interesting since it implies that introducing a forecast may provide a means of shifting from a pooling equilibrium in which either undetected low-quality goods enter the market or one in which the buyer abstains from the market altogether to one in which all sellers are paid the same price but truthfully indicate the current status of their good. Such shifts would not hurt seller welfare in the first period but would hurt seller welfare in period two. Thus in a no-forecast equilibrium in which low-quality goods are consumed, sellers suffer from a forecast. In such cases, seller groups can be expected to be uncooperative in allowing a forecast, unless compensated. In a no-forecast equilibrium in which the market collapses in the first period, however, a win-win solution exists. In such cases, sellers’ expected first-period gain, \( \rho^n c^h \) is greater than their second-period loss, \( \rho^n c^h - (1 - \rho^n) \rho^h c^h \).

6 Conclusion

There is a large literature on markets in which a product’s safety, while known to the seller, is not observable to the consumer at time of purchase. Previous work has examined several mechanisms for overcoming potential market failures arising from this type of asymmetric information. Many of these mechanisms are useful in a wide range of applications, however they each have their limitations. For example, while relevant for experience goods typical models in which producers can use price or advertising as signals of quality do not apply for credence goods. Similarly, the usefulness of warranties or liability rules is limited if sellers lack deep pockets with which to compensate consumers for damages.

We examine a repeated market in which the consumer is in a weak position relative to other models. Not only is the product a credence good for which sellers have limited liability, but sellers have private information regarding both present and future quality and consumers lack the credibility to commit to future decisions that are not time consistent. The only tools initially at the buyer’s disposal are the ability to conduct costly random quality tests and make non-negative payments. We find that these instruments are insufficient to ensure full identification of unsafe products.

If, however, the consumer is able to view an exogenous signal correlated with product quality, this result changes dramatically. The presence of even a noisy signal guarantees that unsafe products do not enter the marketplace undisclosed. It does so not by identifying unsafe goods directly, but by allowing the consumer to give sellers proper incentives to divulge the information voluntarily. In contrast to earlier results by Lizzeri
this model grants a socially useful role to a third-party certification intermediary. Rather than merely appropriating information rents, here their noisy signals can mean the difference between trade and market collapse, or between consumer safety and harm.

As an illustration, we look at the potential role of disease forecasts in a stylized African livestock market. Recent advances in remote sensing technology, climate forecasting, entomological modeling, and the use of sentinel herds have led to efforts to develop forecasting devices to predict disease incidence by geographic area. The potential value of this type of forecast is particularly evident in the livestock trade, in which imports of diseased animals can have damaging effects on human or animal populations.

Fear of disease has caused trade disruption that is harmful to both importers and exporters. Thus, there are hopes that introduction of a disease prediction technology could provide benefits for both groups. In the context of the Rift Valley Fever problem, however, producers are reluctant to provide the information required to calibrate a forecasting device. In this paper, we have developed a simple two-period model of a market with asymmetric information regarding product quality that explains why this may be the case.

If animal health is known only to the seller, there is a cost to owners of sick animals for revealing that information since the buyer is not willing to purchase a sick animal. We show that if sellers are anonymous and reputation is not important (e.g., in the last period of a model with repeated interaction) then there are three potential equilibrium outcomes. If veterinary tests are sufficiently inexpensive all animals are tested, and only healthy ones purchased. If tests are prohibitively expensive there are two other alternatives. If the buyer believes there is a low proportion of sick animals in the population, she simply pays all producers the same price, asks them to reveal the health of their animal, and discards the sick ones. If she believes the proportion to be high, she does not purchase any animals and the market collapses. There is no equilibrium in which diseased animals are consumed.

By relaxing the assumption of anonymous interactions, the model allows for potential equilibria that more closely resemble the stylized facts of the actual market (without a forecast). With repeated interactions in which the health status of a seller’s animals is weakly correlated over time, owners of sick animals in the first period have an even stronger incentive to hide the truth if they expect the buyer to use the information to discriminate against them in the future. Payments sufficiently high to induce these sellers to disclose sick animals may be so high that owners of healthy animals are tempted to lie. In such cases, there is no equilibrium in which the buyer pays all sellers the same price and they reveal their animals’ true health.
Instead, if veterinary testing is prohibitively expensive a pooling equilibrium may arise which is similar to that observed in existing markets: all producers receive the same price, but the buyer cannot identify which animals are healthy. As a result, diseased animals may be unknowingly consumed.

We model the forecast as a prediction of seller-specific second-period disease probabilities based on observations of local environmental characteristics. Introducing a second-period forecast to the model results is a net welfare gain for society if buyer and seller welfare receive the same weight. The gains are not equally shared, however. A forecast unambiguously helps buyers in two ways. First, it allows them to screen out those sellers most likely to have sick animals. This result is similar to the benefits from forecasts identified in other contexts such as planting or grazing decisions. Intuitively, the forecast allows the buyer to make better ex ante decisions. As a corollary, improvements in forecast skill further help buyers by reducing the probability that they screen out healthy animals.

The second way forecasts help buyers is by changing seller incentives in period one. With a forecast, sellers with sick animals in period one require less compensation to reveal their type than in the model without forecasts since it is rational for them to believe that the buyer will not use this information to discriminate against them later. As a result, the second-period forecast indirectly helps the buyer in period one by relaxing incentive constraints. The first-period forecast equilibria are exactly the same as those in the second period. In other words, even a noisy forecast signal can eliminate the possibility of equilibria in which diseased animals are consumed.

Introduction of a forecast is not so beneficial for the sellers. The only way a forecast can help a seller in period two is if it causes the buyer to contract with him when she would have otherwise avoided him. For example, suppose the market would have collapsed without a forecast. By allowing the buyer to screen some sellers with sick animals, she may be able to profitably contract with the rest. Those with whom she does contract can then expect to benefit from the forecast. However, once a forecast is sufficiently precise that buyers use it rather than a seller’s previous history, the average seller is unambiguously hurt by any increases in forecast precision.

In period one, the effect of a forecast on seller welfare is ambiguous. If the audit cost is sufficiently low that random first-period audits are an equilibrium (but not so low that audits are deterministic), then expected seller first-period profit is reduced by a second-period forecast. If the no-forecast equilibrium was characterized by the purchase of undetected sick animals, then introduction of a forecast enables the buyer
to elicit the true animal health from the sellers (since she can credibly commit to ignore it in the second period), but does not reduce seller income. Thus, there may be scope for a forecast to eliminate equilibria involving consumption of sick animals without harming sellers in period one, although they will suffer a loss in income in period two.

These results have strong implications regarding the political economy of introducing noisy signals of safety in markets for credence goods. First, organizations interested in promoting a signaling technology should be aware that although it can help sellers, it also has the potential to make them worse off. This latter effect can be important if sellers are politically important. Second, since a signal improves social welfare by the Kaldor-Hicks criterion, the buyer should be willing to compensate sellers for any expected losses and still be better off with the forecast. Third, if such a compensation scheme is not practically implementable, seller resistance to the implementation of a signaling device should be increasing in its precision. In other words, to minimize resistance from sellers, the forecast should have just enough precision that the buyer can credibly commit to discriminate based on its signal rather than a seller’s past type. Any improvement in precision beyond that point reduces seller welfare and may jeopardize political feasibility.

Appendix

Proof of Lemma 1 Recall that the minimum payment at which a type $c^h$ is willing to sell is $c^h$. We check to ensure that setting his payment to either $c^h$ or zero does not violate IC constraints. In either case, the left-hand side of constraint (5) is zero. Consider the value of the right-hand side of constraint (5) corresponding to $g_2^s (c^f) = 0$. If $g_2^s (c^f) = 0$, IC for type $c^f$ requires $P_2^s (c^f|a^n) \geq [1 - g_2^s (c^h)] P_2^s (c^h|a^n)$. It is optimal for the buyer to reduce $P_2^s (c^f|a^n)$ until this condition holds as an equality since doing so reduces her expected cost without violating any constraints. Substitution of $[1 - g_2^s (c^h)] P_2^s (c^h|a^n)$ for $P_2^s (c^f|a^n)$ in the IC condition for type $c^h$ implies that satisfaction of (5) requires $0 \geq q^s (c^f, c^h|a^n) [1 - g_2^s (c^h)] P_2 (c^h|a^n) - c^h$. If $P_2^s (c^h|a^n)$ is either $c^h$ or zero this condition is necessarily satisfied. Since satisfaction of IC for type $c^h$ is guaranteed even if $g_2^s (c^f) = 0$, it must not be optimal for the buyer to undertake costly audits of type $c^f$ contracts.

Proof of Proposition 1 First note from (6) that the buyer’s problem is linear in $g^s (c^h)$. Therefore, either zero or one is an optimal value of $g^s (c^h)$. By Lemma 1, the expected payment received by a healthy declaration ($P_2^s (c^h|a^n)$ if $g_2^s (c^h) = 0$, and $P_2^s (c^h|a^y)$ if $g_2^s (c^h) = 1$) is either $c^h$ or zero. If $g_2^s (c^h) = 0$ and $P_2^s (c^h|a^n) = c^h$ then type $c^f$ sellers receive $c^h$, otherwise they receive zero. The buyer’s second-period
expected utility for each of the combinations of type $c^h$ audit probabilities and prices is summarized in the following table. The equilibrium expected utility is the cell with the highest value.

Table 2: Possible period two equilibrium buyer utility

<table>
<thead>
<tr>
<th>Payment to $c^h =$</th>
<th>0</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$g_2^2(c^h)$</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>$[1 - \rho^s] v^h - c^h$</td>
<td>[1 - $\rho^s$, $v^h - \alpha - c^h$]</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>C</td>
<td>0</td>
</tr>
</tbody>
</table>

Proof of Proposition 2 First consider candidates for pooling equilibria. Note from (13) that the buyer’s utility is linear in $g_1^u(c^0)$ regardless of the value of $P_1^u(c^0|a^n)$. If $g_1^u(c^0) = 0$, the buyer does not learn any new information regarding the sellers’ first-period types. Her first-period utility is either

A. $0$; or

B. $[1 - \rho^u] v^h - c^h + \rho^u v^\ell$

depending on whether the buyer purchases or not. Which of these two utility levels is higher depends upon the expected damage from unknowingly purchasing a low-quality good. If $g_1^u(c^0) = 1$, then the value of $P_1^u(c^0|a^n)$ is irrelevant. The buyer learns the type of all sellers from the audit, therefore her expected second-period utility from this contract is the same as that from separating equilibria. Her expected first-period utility from this contract is

C. $[1 - \rho^u] [v^h - c^h] - \alpha$.

There are four candidate categories of separating equilibria depending on the values of the audit probabilities: $g_1^u(c^\ell) > 0$ and $g_1^u(c^h) > 0$; $g_1^u(c^\ell) > 0$ and $g_1^u(c^h) = 0$; $g_1^u(c^\ell) = 0$ and $g_1^u(c^h) > 0$; and $g_1^u(c^\ell) = 0$ and $g_1^u(c^h) = 0$.

First consider the category of contracts for which $g_1^u(c^\ell) > 0$ and $g_1^u(c^h) = 0$. Note that for any given value $P'$ of expected payments to type $c^\ell$, it is optimal for the buyer to set $P_1^u(c^\ell|a^n) = 0$ and to choose $P_1^u(c^\ell|a^n)$ such that $g_1^u(c^\ell) Q_1^u(c^\ell|a^n) [P_1^u(c^\ell|a^n) - c^h] = P'$. Doing so holds constant expected payments...
for type $c^f$ while reducing the right hand side of IC constraint (11) for type $c^h$. For type $c^h$, constraint (11) then simplifies to $Q_1^u (c^h | a^n) \left[ P_1^u (c^h | a^n) - c^h \right] \geq -\rho^h c^h$. Since the right-hand side of this expression is less than or equal to zero and the left-hand side is greater than or equal to zero, any payments are sufficient to satisfy IC for $c^h$. It is therefore optimal for the buyer to set $P_1^u (c^h | a^n) = c^h$ if it wishes to purchase from an unaudited type $c^h$, and $P_1^u (c^h | a^n) = 0$ otherwise. For type $c^f$, constraint (11) simplifies to $g_1^u (c^f) P_1^u (c^f | a^y) = P_1^u (c^h | a^n) + \rho c^h$. In equilibrium this constraint binds since otherwise the buyer could reduce her expenditure holding all else equal by reducing $P_1^u (c^f | a^y)$. The buyer’s first-period utility is then

\begin{equation}
[1 - \rho^u] [v^h - c^h] - \rho^u g_1^u (c^f) \left[ P_1^u (c^h | a^n) + \rho c^h \right] g_1^u (c^f) + \alpha] .
\end{equation}

Since this expression is strictly decreasing in $g_1^u (c^f)$ the buyer would like to set this probability as low as possible, correspondingly raising $P_1^u (c^f | a^y)$. Due to the upper bound on payments, the smallest possible value of $g_1^u (c^f)$ is $P_1^u (c^h | a^n) + \rho c^h$. Depending on the decision to buy from an unaudited type $c^h$, the buyer’s first period utility is either

\begin{enumerate}
\item[D.] $[1 - \rho^u] v^h - c^h + \rho^u \rho - \frac{c^h \rho^u [1 + \rho^f] [\bar{\rho} + \alpha]}{\rho}$; or
\item[E.] $-\frac{c^h \rho^u [\bar{\rho} + \alpha]}{\rho}$
\end{enumerate}

Next consider the category of contracts for which $g_1^u (c^f) = 0$ and $g_1^u (c^h) > 0$. For type $c^f$, constraint (11) simplifies to $P_1^u (c^f | a^n) = \left[ 1 - g_1^u (c^h) \right] \left[ P_1^u (c^h | a^n) + \rho c^h \right]$. In equilibrium this constraint binds since otherwise the buyer could reduce her expenditure holding all else equal by reducing $P_1^u (c^h | a^n)$. For type $c^h$, constraint (11) then simplifies to $\Pi_1^u (c^h) \geq g_1^u (c^f, c^h | a^n) \left[ [1 - g_1^u (c^h)] \left[ P_1^u (c^h | a^n) + \rho c^h \right] - c^h \right] - c^h \rho^h$. If the buyer wishes to purchase from an unaudited type $c^h$ then $P_1^u (c^h | a^n) = c^h$ (setting $P_1^u (c^h | a^n) > c^h$ would raise the buyer’s expenses while making it more difficult to satisfy IC for both types). If $P_1^u (c^h | a^n) = c^h$, constraint (11) for type $c^h$ can further be simplified to

\[ g_1^u (c^h) Q_1^y (c^h | a^y) \left[ P_1^u (c^h | a^y) - c^h \right] \geq c^h \left[ g_1^u (c^f, c^h | a^n) \left[ [1 - g_1^u (c^h)] \left[ 1 + \rho^f \right] - 1 \right] - \rho^h \right] . \]

If $g_1^u (c^h) \geq \frac{c^h - c^h}{1 + \rho^f}$ then the right-hand side of this expression is less than or equal to zero and this constraint is necessarily satisfied for any $P_1^u (c^h | a^y)$. Consequently, $P_1^u (c^h | a^y) = c^h$ if the buyer wishes to purchase from an audited type $c^h$, since setting $P_1^u (c^h | a^y) > c^h$ only increases the buyer’s expected payments. If
$g_1^u (c^h) < \frac{\rho^e - \rho^h}{1 + \rho^e}$ and $P_1^u (c^h|a^u) = c^h$, then $q_1^u (c^e, c^h|a^u) = 1$ (since the net payment from choosing a type $c^e$ contract is $c^h \rho^e > 0$) and IC for type $c^h$ requires $g_1^u (c^h) Q_1^u (c^h|a^u) \left[ P_1^u (c^h|a^u) - c^h \right] > 0$, which in turn requires that $P_1^u (c^h|a^u) > c^h$ and $Q_1^u (c^h|a^u) = 1$. If $g_1^u (c^h) < \frac{\rho^e - \rho^h}{1 + \rho^e}$ and $P_1^u (c^h|a^u) = c^h$, the minimum value of $P_1^u (c^h|a^u)$ that can satisfy IC is $P_1^u (c^h|a^u) = \frac{c^h}{g_1^u (c^h)} \left[ [1 - g_1^u (c^h)] \rho^e - \rho^h \right]$. Since the upper bound on payments is $\bar{p}$, the corresponding minimum value for $g_1^u (c^h)$ is $\frac{c^h [\rho^e - \rho^h]}{\rho^e + \rho^h}$. To summarize: if $g_1 (c^e) = 0$ and $P_1^u (c^h|a^u) = c^h$ then a separating equilibrium requires

\[
P_1^u (c^h|a^u) = \begin{cases} 
0 & \text{for } g_1^u (c^h) < \frac{\rho^e - \rho^h}{1 + \rho^e} \\
\frac{c^h}{g_1^u (c^h)} \left[ [1 - g_1^u (c^h)] \rho^e - \rho^h \right] & \text{for } g_1^u (c^h) \geq \frac{\rho^e - \rho^h}{1 + \rho^e}
\end{cases}
\]

The buyer's first-period utility is then

\[
[1 - \rho^u] \left[ g_1^u (c^h) \left[ Q (c^h|a^u) [v^h - P_1^u (c^h|a^u)] - \alpha \right] + [1 - g_1^u (c^h)] [v^h - c^h] \right] - \rho^u \left[ 1 - g_1^u (c^h) \right] [1 + \rho^e] c^h,
\]

subject to (15). Regardless of the value of $g_1^u (c^h)$, the buyer is better off setting $P_1^u (c^h|a^u) = c^h$ than zero. It is therefore optimal for the buyer to set $P_1^u (c^h|a^u) \geq c^h$, and we can safely set $Q (c^h|a^u) = 1$. Note further that this utility function is piecewise linear in $g_1^u (c^h)$. For $g_1^u (c^h) > \frac{\rho^e - \rho^h}{1 + \rho^e}$ its slope is $c^h \rho^u [1 + \rho^e] - [1 - \rho^u] \alpha$. For $\frac{\rho^e - \rho^h}{1 + \rho^e} \leq g_1^u (c^h) < \frac{\rho^e - \rho^h}{1 + \rho^e}$ its slope is $c^h [1 + \rho^e] - [1 - \rho^u] \alpha$. There are thus potentially three equilibria in this category. If $[1 - \rho^u] \alpha \leq c^h \rho^u [1 + \rho^e]$ then $g_1^u (c^h) = 1$ and the buyer's first-period utility is

\[
F. \quad [1 - \rho^u] [v^h - c^h - \alpha]
\]

If $c^h [\rho^e + 1] \geq [1 - \rho^u] \alpha > c^h \rho^u [1 + \rho^e]$, then $g_1^u (c^h) = \frac{\rho^e - \rho^h}{1 + \rho^e}$ and the buyer's utility is

\[
[1 - \rho^u] \left[ \frac{\rho^e - \rho^h}{1 + \rho^e} [v^h - c^h - \alpha] + [1 - \frac{\rho^e - \rho^h}{1 + \rho^e}] [v^h - c^h] \right] - \rho^u \left[ 1 - \frac{\rho^e - \rho^h}{1 + \rho^e} \right] [c^h + \rho^e c^h],
\]

which simplifies to

\[
G. \quad [1 - \rho^u] v^h - c^h - \rho^u \rho^e c^h + \frac{\rho^e - \rho^h}{1 + \rho^e} [\rho^u c^h [1 + \rho^e] - [1 - \rho^u] \alpha].
\]
If \([1 - \rho^u] \alpha > c^h [\rho^e + 1]\), then \(g^u_1 (c^h) = \frac{c^h [\rho^e - \rho^h]}{p + c^h \rho^h}\), and the buyer’s utility is

\[
[1 - \rho^u] \left[ \frac{c^h [\rho^e - \rho^h]}{p + c^h \rho^h} \right] [v^h - \bar{p} - \alpha] + \left[ 1 - \frac{c^h [\rho^e - \rho^h]}{p + c^h \rho^h} \right] [v^h - c^h] - c^h \rho^u \left[ 1 - \frac{c^h [\rho^e - \rho^h]}{p + c^h \rho^h} \right] [1 + \rho^e],
\]

which simplifies to

\[
H. \quad [1 - \rho^u] v^h - c^h - c^h \rho^u \rho^h + \frac{c^h [\rho^e - \rho^h]}{p + c^h \rho^h} \left[ c^h [1 + \rho^e] - [1 - \rho^u] \alpha \right] - c^h \left[ \rho^e - \rho^h \right].
\]

If the buyer does not purchase from an unaudited \(c^h\) declaration, then \(P^u_1 (c^h | a^y) = 0\) and constraint (11) becomes

\[
g^u_1 (c^h) Q^u_1 (c^h | a^y) [P^u_1 (c^h | a^y) - c^h] \geq c^h \left[ g^u_1 (c^e, c^h | a^y) \left[ [1 - g^u_1 (c^h)] \rho^e - 1 \right] - \rho^h \right].
\]

Since the right hand side of this expression is negative, IC is satisfied for all \(P^u_1 (c^h | a^y)\). The buyer’s first period utility is then

\[
[1 - \rho^u] g^u_1 (c^h) [Q^u_1 (c^h | a^y) [v - P^u_1 (c^h | a^y)] - \alpha] - \rho^u [1 - g^u_1 (c^h)] \rho^e c^h.
\]

As before, the optimal value of \(P^u_1 (c^h | a^y)\) is \(c^h\). The buyer’s utility function is now linear in \(g^u_1 (c^h)\). For \(g^u_1 (c^h) = 1\), buyer utility is

\[
(20) \quad I. \quad [1 - \rho^u] [v - c^h - \alpha].
\]

At the other extreme, the limit of utility as \(g^u_1 (c^h)\) approaches zero is

\[
(21) \quad J. \quad -c^h \rho^u \rho^e.
\]

Consider now the category of contracts for which \(g_1 (c^e) > 0\) and \(g_1 (c^h) > 0\) is an equilibrium. In this case, constraint (11) simplifies to \(\Pi^u_1 (c^h) \geq -c^h \left[ 1 - g^u_1 (c^h) \right] [1 + \rho^h]\). Since the right-hand side of this expression is less than or equal to zero, the constraint is satisfied for any \(P^u_1 (c^h | a^h)\) and \(P^u_1 (c^h | a^u)\). Thus, in equilibrium the buyer pays \(c^h\) if she wishes to purchase from an audited or unaudited type \(c^h\),
zero otherwise. Due to the upper bound on payments, the minimum value of \( g_1^u (c^f) \) is \( \frac{P_{1}^u (c^h|a^n) + \rho' c^h}{p} \). For \( g_1^u (c^f) \geq \frac{P_{1}^u (c^h|a^n) + \rho' c^h}{p} \), the buyer’s first-period utility is

\[
[1 - \rho^n] [g_1^u (c^h) [v^h - c^h - \alpha] - c_p^n \rho^f n + \frac{n}{p}] + [1 - g_1^n (c^h)] Q_1^n (c^h|a^n) [v^h - P_1^n (c^h|a^n)]
\]

\[
- \rho^n g_1^n (c^f) \left[ \frac{[1 - g_1^n (c^h)] [P_1^n (c^h|a^n) + \rho' c^h]}{g_1^n (c^f)} \right] + \alpha.
\]

Note again that it is optimal for the buyer to set \( P_1^n (c^h|a^n) = c^h \). Further, since the derivative of utility with respect to \( g_1^n (c^f) \) is \( -\rho^n \alpha < 0 \), in equilibrium \( g_1^n (c^f) = \frac{P_1^n (c^h|a^n) + \rho' c^h}{p} \) (the minimum possible). Depending on the decision to purchase from unaudited type \( c^h \) sellers, utility can be expressed as either

\[
[1 - \rho^n] [g_1^n (c^h) [v^h - c^h - \alpha] - c_p^n \rho^f n + \frac{n}{p}] \quad \text{if} \quad P_1^n (c^h|a^n) = 0, \text{ or}
\]

\[
[1 - \rho^n] [v^h - c^h - g_1^n (c^h) \alpha] - c_p^n \left[ 1 + \rho^f \right] \left[ 1 - g_1^n (c^h) + \frac{n}{p} \right] \quad \text{if} \quad P_1^n (c^h|a^n) = c^h.
\]

Both these expressions are linear in \( g_1^n (c^h) \). The utility levels evaluated at \( g_1^n (c^h) = 1 \) and at the limit as \( g_1^n (c^h) \) approaches zero are either

K. \[ [1 - \rho^n] [v^h - c^h - \alpha] - \frac{c^h \rho^n \rho' \alpha}{p} \]

L. \[ - \frac{c^h \rho^n \rho' \alpha}{p} \]

if \( P_1^n (c^h|a^n) = 0, \) or

M. \[ [1 - \rho^n] [v^h - c^h - \alpha] - \frac{c^h \rho^n [1 + \rho^f] \alpha}{p} \]

N. \[ [1 - \rho^n] [v^h - c^h] - \frac{c^h \rho^n [1 + \rho^f] \alpha}{p} \]

if \( P_1^n (c^h|a^n) = c^h \).

Finally, consider the category of contracts for which \( g_1 (c^f) = 0 \) and \( g_1 (c^h) = 0 \) is a separating equilibrium. In this case constraint (11) for type \( c^h \) simplifies to

\[
Q_1^n (c^h|a^n) \left[ P_1^n (c^h|a^n) - c^h \right] \geq q_1^n (c^f, c^h|a^n) \left[ P_1^n (c^h|a^n) + \rho' c^h - c^h \right] - \rho^n \alpha.
\]

If the buyer decides not to purchase from type \( c^h \), then \( P_1^n (c^h|a^n) = 0 \) and this constraint becomes \( 0 \geq -\rho^n c^h \), which is necessarily satisfied. If, however, \( P_1^n (c^h|a^n) \geq c^h \) the constraint becomes \( 0 \geq c^h \left[ \rho^f - \rho^n \right] \),
which cannot be satisfied. Therefore a separating equilibrium with $g_1 (c^f) = 0$ and $g_1 (c^h) = 0$ can only exist if $P^u_1 (c^h|a^n) = 0$. If $P^u_1 (c^h|a^n) = 0$, IC for type $c^f$ requires $P^u_1 (c^f|a^n) = c^h \rho^f$. In such a case, the buyer’s first-period expected utility is

\[(24) \quad \hat{U}_2 = -c^h \rho^u \rho^f.\]

For any separating equilibrium, the buyer uses first-period seller contract choice to infer each seller’s first-period type since it is incentive compatible for the sellers to reveal their types in this manner. Recall that we assume that the expected second-period buyer utility of contracting with sellers for whom $c_1 = c^f$ is negative. As a result, in a separating equilibrium, the buyer will only contract in period two with sellers for whom $c_1 = c^h$. Her expected second-period utility from engaging in this type of discrimination is $\hat{U}_2^h$. At the beginning of period one, her expected second-period utility from any separating equilibrium is $[1 - \rho^u] \hat{U}_2^h$ (the probability of encountering a type $c^h$ in period one multiplied by the expected second-period utility obtained from sellers for whom $c_1 = c^h$). The buyer’s expected second-period utility from a pooling equilibrium in which she does not learn seller types is $\hat{U}_2^u$.

Table 3: Candidate Pooling First-Period Contract Terms

| Contract Terms | $g (c^n)$ | $P (c^h|a^n)$ | $P (c^f|a^n)$ | $P (c^h|a^y)$ |
|----------------|----------|---------------|---------------|----------------|
| A.             | 1        | 0             | $c^h$         |                |
| B.             | 0        | 0             |               | $c^h$         |
| C.             | 0        | $c^h$         |               |                |

Tables 3, 4, and 5 summarize the results thus far regarding fifteen candidate equilibria buyer expected (as of the beginning of period one) utility levels over both periods as a function of the first-period contract terms. The first three correspond to candidates for pooling equilibria, while the final twelve correspond to candidates for separating equilibria. We can shorten this list by eliminating candidates that are weakly dominated by others. For example, since by Proposition 1

\[
\hat{U}_2^u \geq \left[ 1 - \rho^u \right] v^h - c^h
\]

\[
\geq \left[ 1 - \rho^u \rho^f - \left( 1 - \rho^u \right) \rho^h \right] v^h - c^h
\]

\[
\geq \left[ 1 - \rho^u \right] \hat{U}_2^h + \rho^u \left[ 1 - \rho^f \right] \left[ v^h - c^h \right] - \rho^u \rho^f c^h,
\]

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it must be the case that $B$ dominates $E$, $J$, $L$, and $O$. Similarly, $D$ dominates $N$, and $I$ weakly dominates $A$, $F$, $K$, and $M$. As a result, there is no loss in generality in restricting attention to contract terms that yield the six possible equilibria listed in Proposition 2.

Proof of Lemma 2 In period two, equilibrium expected buyer utility if a forecast is available is $\hat{U}_2^\phi$, where, by the law of iterated expectations,

$$\hat{U}_2^\phi = E_{\rho^h} \left[ v^h [1 - \rho^h] - c^h | \rho^\phi < \hat{\rho} \right] F^\phi (\hat{\rho})$$

$$= E_{\rho^h} \left[ E_{c_1} \left[ v^h [1 - \rho^h] - c^h \right] F^{\phi | c_1} (\hat{\rho} | c_1) | \rho^\phi < \hat{\rho} \right]$$

$$= \rho^n \int_0^{\hat{\rho}} [1 - \rho] v^h - c^h f^{\phi | c_1} (\rho | c^h) d\rho + [1 - \rho^n] \int_0^{\hat{\rho}} [1 - \rho] v^h - c^h f^{\phi | c_1} (\rho | c^h) d\rho. \quad (25)$$

First, consider problems in which there is a separating equilibrium in the first period. In such equilibria, without a forecast the buyer only purchases from sellers with signal $h$ in period two. Her expected second-period utility is

$$[1 - \rho^n] \hat{U}_2^h = [1 - \rho^n] [1 - \rho^h] v^h - c^h$$

$$= [1 - \rho^n] \int_0^1 [1 - \rho] v^h - c^h f^{\phi | c_1} (\rho | c^h) d\rho. \quad (26)$$

Table 4: Candidate Separating First-Period Contract Terms

| Contract | $g(c^h)$ | $g(c^l)$ | $P(c^h|a^l)$ | $P(c^l|a^l)$ | $P(c^h|a^l)$ | $P(c^l|a^l)$ |
|----------|----------|----------|---------------|---------------|---------------|---------------|
| D.       | $c^h[1 + \rho^\phi]$ | 0         | 0             | $c^h$         | $\bar{p}$     | $-$           |
| E.       | $\rho^c c^h$ | 0         | 0             | 0             | $\bar{p}$     | $-$           |
| F.       | 0         | 1         | 0             | -             | -             | $c^h$         |
| G.       | 0         | $\rho^c - \rho^h$ | $[1 + \rho^h] c^h$ | $c^h$         | -             | $c^h$         |
| H.       | 0         | $c^h[1 + \rho^h] c^h$ | $[1 + \rho^h][\bar{p} + c^h \rho^h]$ | $c^h$         | -             | $\bar{p}$     |
| I.       | 0         | 1         | 0             | -             | -             | $c^h$         |
| J*       | 0         | 0         | $\rho^h c^h$ | $c^h$         | -             | $c^h$         |
| K.       | $\rho^c c^h$ | 1         | 0             | -             | $\bar{p}$     | $c^h$         |
| L*       | $\rho^c c^h$ | 0         | 0             | $c^h$         | $\bar{p}$     | $c^h$         |
| M.       | $\rho^c[1 + \rho^h]$ | 1         | 0             | -             | $\bar{p}$     | $c^h$         |
| N*       | $\rho^c[1 + \rho^h]$ | 0         | 0             | $c^h$         | $\bar{p}$     | $c^h$         |
| O.       | 0         | 0         | $c^h \rho^c$ | 0             | -             | -             |

Note: *Evaluated at the limit as $g(c^l)$ approaches zero.
The right-hand side of Eq. (27) is positive since
the difference between (25) and (26) is

\[
(27) \quad \hat{U}_2 - [1 - \rho^u] \hat{U}_2 = \rho u \int_0^\hat{\rho} [1 - \rho] v^h - c^h \int f^\phi |c_i^1 (\rho | c^f) d\rho - [1 - \rho^u] \int_0^1 [1 - \rho] v^h - c^h \int f^\phi |c_i^1 (\rho | c^h) d\rho
\]

The first term on the right-hand side of Eq. (27) indicates the expected benefits gained by the buyer from purchasing from those sellers with an \( \ell \) signal that she would have otherwise refused. The second term indicates the losses avoided by refusing sellers with an \( h \) signal from whom she would have otherwise purchased.

The right-hand side of Eq. (27) is positive since \([1 - \rho^\phi] v^h - c^h < 0\) for \( \rho^\phi > \hat{\rho} \).

Next, consider first-period pooling equilibria. Without a forecast the buyer purchases from all sellers in period two. Her expected second-period utility is

\[
\hat{U}_2 = [1 - \rho^u] v^h - c^h
\]

\[
= \int_0^1 [1 - \rho] v^h - c^h \int f^\phi (\rho) d\rho.
\]
The difference between (25) and (28) is

\[
\hat{U}_2^\phi - \hat{U}_2^u = - \int_\phi^1 \left[ [1 - \rho] v^h - c^h \right] f^\phi(\rho) \, d\rho,
\]

which is the expected savings from refusing sellers with a \(u\) signal from whom she would have otherwise purchased.\(\blacksquare\)

\textit{Proof of Lemma 3} First consider a separating equilibrium. The expected profit of a seller with an \(\ell\) signal without the forecast is \(E \left[ \Pi_2^\ell (c_2) \right] = 0\). The expected profit of a seller with an \(h\) signal without the forecast is

\[
E \left[ \Pi_2^h (c_2) \right] = \rho^h c^h
\]

\[
= \int_0^1 c^h \rho f^{\phi|c_1} (\rho|c^h) \, d\rho.
\]

Thus, before a seller knows his first-period type, his expected second-period profit is

\[
E \left[ E_{c_2} \left[ \Pi_2^h (c_2) \right] \mid c_1 = c^* \right] = \left[ 1 - \rho^u \right] \rho^h c^h.
\]

With a forecast, the second-period profit of a seller conditional on \(\phi\) and \(c_2\) is

\[
\Pi_2^\phi (c_2) = \begin{cases} 
  c^h & \text{for } \rho^\phi \leq \hat{\rho} \text{ and } c_2 = c^\ell, \\
  0 & \text{otherwise}.
\end{cases}
\]

Expected second-period profit for a seller with an \(\ell\) signal is

\[
E_{\rho^\phi} \left[ E_{c_2} \left[ \Pi_2^\phi (c_2) \mid c_1 = c^\ell \right] \right] = \int_0^{\hat{\rho}} c^h \rho f^{\phi|c_1} (\rho|c^\ell) \, d\rho,
\]

and the expected profit of a seller with an \(h\) signal is

\[
E_{\rho^\phi} \left[ E_{c_2} \left[ \Pi_2^\phi (c_2) \mid c_1 = c^h \right] \right] = \int_0^{\hat{\rho}} c^h \rho f^{\phi|c_1} (\rho|c^h) \, d\rho.
\]
Before knowing $c_1$, a seller’s expected second-period profit is therefore

$$E_{c_1} \left[ E_{c^\phi} \left[ E_{c_2} \left[ \Pi_2^\phi (c_2) | \rho^\phi \right] | c_1 \right] \right] = \rho^u \int_0^{\hat{\rho}} c^h \rho f_{\phi|c_1} (\rho | c^\ell) \, d\rho + \left[ 1 - \rho^u \right] \int_0^{\hat{\rho}} c^h \rho f_{\phi|c_1} (\rho | c^h) \, d\rho \tag{35}$$

Thus, whether the introduction of a forecast improves sellers’ expected second-period welfare depends upon the sign of the term in braces on the right hand side of Eq. (35).

For a pooling equilibrium, without a forecast expected profit of a seller for whom $c_1 = c^\ell$ is

$$E \left[ \Pi_2^\ell (c_2) \right] = \int_0^1 c^h \rho f_{\phi|c_1} (\rho | c^\ell) \, d\rho. \tag{36}$$

Expected profit of a seller for whom $c_1 = c^h$ is

$$E \left[ \Pi_2^h (c_2) \right] = \int_0^1 c^h \rho f_{\phi|c_1} (\rho | c^h) \, d\rho. \tag{37}$$

Before knowing $c_1$, a seller’s expected second-period profit without a forecast is therefore

$$E \left[ \Pi_2^f (c_2) \right] = \rho^u \int_0^1 c^h \rho f_{\phi|c_1} (\rho | c^\ell) \, d\rho + \left[ 1 - \rho^u \right] \int_0^1 c^h \rho f_{\phi|c_1} (\rho | c^h) \, d\rho \tag{38}$$

Sellers’ ex ante second-period benefit from a forecast is indicated by the difference between Eq. (35) and Eq. (38),

$$-c^h \left[ \rho^u \int_0^1 \rho f_{\phi|c_1} (\rho | c^\ell) \, d\rho + \left[ 1 - \rho^u \right] \int_0^1 \rho f_{\phi|c_1} (\rho | c^h) \, d\rho \right],$$

which is negative. 

**Proof of Lemma 4.** The buyer’s prefers forecast $\phi$ to forecast $\phi$ if her second-period welfare is no lower for any values of $v^h$ and $c^h$ and higher for some values. Since the buyer purchases from all sellers with signal
lower than \( \hat{\rho} \), this implies that, for all \( v^h \) and \( c^h \),

\[
E \left[ v^h [1 - \rho^\varphi] - c^h | \rho^\varphi < \hat{\rho} \right] F^\varphi (\hat{\rho}) \geq E \left[ v^h [1 - \rho^\varphi] - c^h | \rho^\varphi < \hat{\rho} \right] F^\phi (\hat{\rho})
\]

\[
\int_0^{\hat{\rho}} \left[ v^h [1 - \rho] - c^h \right] f^\varphi (\rho) d\rho \geq \int_0^{\hat{\rho}} \left[ v^h [1 - \rho] - c^h \right] f^\phi (\rho) d\rho
\]

\[
F^\varphi (\hat{\rho}) \left[ v^h - c^h \right] - v^h \int_0^{\hat{\rho}} \rho f^\varphi (\rho) d\rho \geq F^\phi (\hat{\rho}) \left[ v^h - c^h \right] - v^h \int_0^{\hat{\rho}} \rho f^\phi (\rho) d\rho
\]

where the last step follows from integration by parts (and the inequality is strict for some \( v^h \) and \( c^h \)). By the definition \( \hat{\rho} \equiv (v^h - c^h) / v^h \), the last inequality simplifies to

\[
\int_0^{\hat{\rho}} F^\varphi (\rho) d\rho \geq \int_0^{\hat{\rho}} F^\phi (\rho) d\rho \text{ for all } \hat{\rho} \in [0, 1] \text{ and}
\]

\[
\int_0^{\hat{\rho}} F^\varphi (\rho) d\rho > \int_0^{\hat{\rho}} F^\phi (\rho) d\rho \text{ for some } \hat{\rho} \in [0, 1].
\]

This last set of inequalities is a definition of second-order stochastic dominance of \( F^\phi \) over \( F^\varphi \) (see, for example Hirshleifer and Riley, 1992). □

**Proof of Proposition 3.** For Part i, note that by the law of iterated expectations, the ex ante second-period welfare of all sellers whose forecast probability of being type \( \varphi \) is lower than \( \hat{\rho} \) is unambiguously lower with \( \varphi \) than with \( \phi \):

\[
E_{c_1} \left[ v^h [1 - \rho^\varphi] - c^h | \rho^\varphi < \hat{\rho}, c_1 \right] F^{\phi | c_1} (\hat{\rho} | c_1) = c^h E \left[ v^h [1 - \rho^\varphi] - c^h | \rho^\varphi < \hat{\rho} \right] F^\phi (\hat{\rho})
\]

\[
> c^h E \left[ v^h [1 - \rho^\varphi] - c^h | \rho^\varphi < \hat{\rho} \right] F^\varphi (\hat{\rho}),
\]

where the inequality comes from the fact that \( F^\phi \) second-order stochastically dominates \( F^\varphi \). For Part iii, combined expected second-period welfare for buyer and sellers from \( \phi \) is

\[
E_{c_1} \left[ v^h [1 - \rho^\varphi] - c^h | \rho^\varphi < \hat{\rho}, c_1 \right] F^{\phi | c_1} (\hat{\rho} | c_1) + E \left[ v^h [1 - \rho^\varphi] - c^h | \rho^\varphi < \hat{\rho} \right] F^\varphi (\hat{\rho})
\]

\[
= c^h \int_0^{\hat{\rho}} \rho f^\varphi (\rho) d\rho + \int_0^{\hat{\rho}} \left[ v^h [1 - \rho] - c^h \right] f^\varphi (\rho) d\rho
\]

\[
= \int_0^{\hat{\rho}} v^h [1 - \rho] f^\varphi (\rho) d\rho > 0. \ □
\]
Notes

1This notion of a credence good was introduced by Darby and Karni (1973).

2In models where sellers can establish a reputation of honesty it may take several periods before the buyer can distinguish between seller types. In fact, Ely and Välimäki (2003) show that if sellers are longer-lived than buyers even “good” sellers can have an incentive to lie if they are unlucky.

3In the United States for instance, toy manufacturers are required to report potential hazards within 24 hours. In 2007 Mattel was caught selling toys containing lead paint. The CEO stated that “vagaries in the law” led to a “debate ... over what’s timely” in terms of passing along information to regulators. As a result, unsafe products entered the market in spite of the manufacturer’s knowledge (see “Mattel Recalls More Toys for Lead; Toymaker Clashes with CPSC on Timing of Hazard Reports,” USA Today, September 5, 2007). Under the assumption of effective regulation, Polinsky and Shavell (2006) analyze the welfare implications of a mandatory versus voluntary disclosure regime under a variety of product liability rules. Leland (1979) examines the role of minimum quality standards when a licensing agency can costlessly observe quality but consumers cannot.


5In a two-period model of a monopolist selling an experience good Bagwell and Riordan (1991) show how a producer can signal quality by initially charging a high price, then reducing price as consumers learn type. Daughety and Reinganum (1995) examine the relationship between liability rules, pricing and investment in safety by a monopolist. Kihlstrom and Riordan (1984) examine the role of uninformative advertising as a quality signal for an experience good in a competitive equilibrium, while Milgrom and Roberts (1986) show how both price and advertising can signal quality for a monopolist.

6Thus, unlike Spence (1973) a seller’s decision whether to send a signal does not influence the buyer’s beliefs.

7To facilitate the discussion we refer to the buyer in the feminine and sellers in the masculine.
In the RVF case, for example, if someone in Saudi Arabia becomes infected it is not possible to track down the original seller of the lamb. In other cases, a low-quality good may increase the risk of a negative outcome (e.g., cancer), long after consumption.

Note that by Bayes’s Rule $\rho_u = \rho^h / [1 + \rho^h - \rho^c]$.

We assume that the buyer can credibly commit to an audit strategy even if in equilibrium a seller’s type can be inferred by his choice of contract. For models that relax this assumption, see Chen and Liu (2005), Choe (1998), and Khalil (1997).

Since the buyer cannot discriminate between un-audited sellers who choose the same contract, $p^s (\tilde{c}, c^h | a^n) = p^s (\tilde{c}, c^l | a^n)$.

For example, $P_2 (c^h | a^y)$ indicates the second-period payment for a type $c^h$ seller with signal $\rho^*$ who chooses a type $c^h$ contract and is audited.

For an examination of the impact of discount rates on multi-period contracting under adverse selection see Freixas et al. (1985).

Although two of the equilibrium contracts entail identical payments (either $c^h$ or zero) to both types, the buyer can distinguish between types by labelling the contracts as either high or low quality. Incentive compatibility remains satisfied if sellers report their type by choosing their assigned contract.

A subscript on the expectation operator indicates that the expectation is taken over that variable.

For example, option 2 may offer the seller the highest utility out of options 2 through 6. In this case, option 1 will be an equilibrium if $[1 - \rho^u] v^h - c^h > [1 - \rho^u] v^h - c^h + \rho^u v^f > 0$.

From Propositions 1 and 2 and Assumptions 1 and 2, expected buyer total welfare with a forecast is $[1 - \rho^u] v^h - c^h + E [v^h [1 - \rho^u] - c^h | \rho^u < \hat{\rho}] F^\phi (\hat{\rho})$, which is greater than any of the alternatives in Proposition 2.

Whether a seller’s expected utility over both periods is reduced depends on the magnitude of possible second-period gains.
References


