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ENDOGENOUS PUNISHMENTS IN AGENCY WITH VERIFIABLE EX POST INFORMATION*

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The article studies an adverse selection model in which a contractible, imperfect signal on the agent's type is revealed ex post. The agent is wealth constrained, which implies that the maximum penalty depends on the contracted transaction (e.g., the volume of trade). First, we show that the qualitative effects of the signal can be unambiguously tied to the nature of the problem (e.g., whether the agent is in a "buyer" or a "seller" position). Second, the distortions caused by informational asymmetries may become more severe although more information is now available. Finally, the signal can actually serve to increase the agent's informational rents.

1. INTRODUCTION

Informational asymmetries in the form of adverse selection are prevalent in many economic transactions. At the time when two contracting parties meet, one party possesses superior information about a parameter that is relevant to the transaction and, by extension, is of interest for the other party. To give a few examples, an employee may know more about his abilities than his employer, the creditworthiness of a debtor may be unknown to the bank, a lawyer might have better information about the likely outcome of the case than his client, a customer may assess her risks more precisely than the insurance company, or a firm may sell products whose quality is unknown to the consumer. These and many more instances are formally analyzed in a well-known adverse selection framework in which a principal contracts with a privately informed agent. In this workhorse model, all agents other than the "worst" type can command a rent. Also, because of this fact, the contracted decisions for all agents other than the "best" type are distorted downward, away from their first–best levels.

The present article adds to a by now substantial body of literature that studies a natural extension of this standard principal–agent model (a literature survey

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is given below). Namely, we analyze a situation in which information that is correlated with the agent's type becomes available after a contractually specified transaction has taken place. Such additional ex post information seems to be the rule instead of the exception in many empirically relevant circumstances. One set of prominent examples that fit our model are those where the principal actively monitors the agent. In employment or procurement relationships, ex post evaluations and audits reveal information on the agent's true productivity or production costs. Tax authorities will conduct audits to verify taxpayers' reports. Also, franchise contracts are usually contingent not only on sales data, but on the franchisee's behavior (cleanliness, product quality, friendly service), which is regularly monitored by the franchisor.[2] But further information is frequently available even without the principal taking any explicit action. If the agent sells a durable good to the principal, product failure or malfunctioning after the purchase will reveal additional information about the quality of the product. In credit (respectively, insurance) market contexts, changes in independent credit ratings (respectively, an accident) will constitute a verifiable ex post signal about a customer's true risk type on which his interest payment (respectively insurance premium) can be based. Whether a legal dispute is ultimately won or lost will provide a signal about the lawyer's previous assessment on the case's merits on which his compensation can be based. Or consider an upstream firm that contracts as a principal with a downstream firm as an agent over the supply of an intermediate good. The agent's willingness to pay for the input will then be related to the price that is later charged on the downstream market.[3] Finally, ex post information is common in situations where the decisions of other parties are based on information correlated with the agent's type as will be the case in the context of, e.g., auctions, team production, or product market competition.

Previous contributions on ex post information in adverse selection contexts have unambiguously concluded that the availability of additional signals raises allocative efficiency. Indeed, the first best solution is easily attained if unbounded penalties can be imposed on an agent once the signal indicates he did not tell the truth. These penalties effectively eliminate the agent's informational rent, which in turn prompts the principal to implement efficient allocations: As rents are zero, there no longer is a need to distort transactions in an effort to reduce rents. A similar line of argument has been shown to hold in more realistic settings where arbitrarily high punishments are ruled out. Although rents may not drop to zero in this case, they will still be reduced and so will be the principal's benefit from distorting the allocation.

[2] Baron and Besanko (1984) analyze the decision of government agencies to audit tax payers. For an assessment of franchise contracts, see Lafontaine and Slade (1996). In an empirical study of automobile franchising, Arruñada et al. (2001) report that manufacturers condition their contracts on monitoring evidence related to the dealer's sales, customer satisfaction, machinery, personnel, and financial performance, obtained by direct inspections and auditing.

[3] A related point is made by Riley (1988) who argues that the seller of an oilfield will want to condition the buyer's payment on the quantity of oil extracted, which is readily observable and a noisy signal of oilfield profitability.

In line with the latter literature, this article also assumes that the agent is protected by limited liability. We interpret limited liability as the inability of the principal to extract money over and above an exogenous limit from the agent. The primary example would be a situation in which the agent is wealth constrained, which limits total payments to the principal to his (given) wealth. The maximum feasible penalty then depends on the specific terms of contract and is therefore endogenous. The conclusions we draw from our analysis are in striking contrast to those of the previous literature. Our central result is that the total expected surplus of the relationship frequently *falls* as an informative signal becomes publicly available. As a second result, we demonstrate that the direction of the additional distortions that arise crucially depends on the nature of the underlying problem. In particular, if the agent's utility is increasing in the contracted transaction (e.g., the quantity of a good or service he buys from the principal), existing downward distortions will be amplified (the volume of trade further decreases) for signals that are not too informative. Conversely, if the agent's utility is decreasing in the contracted action (e.g., the amount of output he is to produce), the distortions may go in the opposite direction, i.e., the level of the transaction may exceed its first-best level. In this latter scenario, the agent may also command an even *larger* informational rent relative to a situation in which no ex post signal is available. This finding implies that agents may have an incentive to ex post reveal or generate signals about their privately held information to the principal, which again contrasts sharply with the results of previous contributions.

Although additional ex post information can be harmful for efficiency in both situations, the qualitative results differ depending on whether the agent's utility is increasing or decreasing in the contracted transaction (whether he is in a "buyer" or "seller" position). Note that this dichotomy is not found in the standard model without ex post information,[4] and it also cannot arise in settings with ex post signals and exogenously given punishments. Intuitively, our main results and the crucial difference between "buyers" and "sellers," we identify, can be explained as follows. By the maximum punishment principle, a penalty is optimally imposed and set to its maximal level whenever the signal ex post contradicts what the agent has claimed to be true. Consider first an agent in a "buyer" position who is privately informed about his willingness to pay and has only a limited wealth. Now, the smaller the quantity that a low-valuation agent purchases from the principal, the lower the price he has to pay, and the more money is left in the pocket of an untruthful high-valuation agent that can serve as a penalty if the signal indicates noncompliance. Therefore, if the principal wants to increase potential penalties, she decreases the quantity traded beyond the level that would have been optimal in a situation where no ex post information is available. As a result, the total expected surplus falls.

[4] In the standard model, both scenarios lead to less than efficient quantities traded for all types but the "top" agent: What is important is that the single crossing property holds, i.e., absolute and marginal utility move in the same direction as we replace better types (high valuations or low costs) by worse types. This implies that a good-type agent suffers more (or benefits less) from a reduction of the quantity than a bad-type, so that distorting the quantity downward makes it less attractive to mimic worse types. Obviously, this logic does not depend on whether the agent is a "buyer" or a "seller."

The converse argument holds if the agent is in a "seller" position: The higher the amount of output a high-cost agent is to produce, the more he receives in compensation and the more severely can an untruthful low-cost agent be punished if the signal indicates that he has been untruthful. Therefore, the principal optimally increases production and, as we will see, this effect may be sufficiently strong to yield production above the first-best level, so that total surplus may again fall.[5] The agent may then even enjoy a higher rent when ex post information about his type is available ex post. This is because a low-cost agent is affected less than a high-cost agent if the quantity produced rises, i.e., it becomes more attractive for a low-cost type to mimic a high-cost type, ceteris paribus. Finally, note that the extent to which the principal actually wants to increase potential penalties depends on the informativeness of the ex post signal. If the signal is very precise, small penalties are sufficient and therefore the distortion will be weakened (i.e., additional information is welfare enhancing) in both cases.

The remainder of the article is organized as follows. Section 2 surveys the existing body of literature on ex post signals in adverse selection frameworks. Section 3 introduces the model. The optimal contract in the presence of a verifiable ex post signal is derived and discussed in Section 4. A final section concludes. All proofs are relegated to the Appendix.

2. LITERATURE REVIEW

Agency models with asymmetric information start out from the presumption that the principal possesses knowledge of the prior distribution according to which the agent's unknown type is distributed. The optimal contract then entails an output distortion for all types other than the most efficient type (Baron and Myerson, 1982; Laffont and Tirole, 1993). The subsequent literature has shown that this outcome can be significantly improved if the parties can make their contractual arrangement contingent on a signal that is realized after the agent reported his type. Under these circumstances, Nalebuff and Scharfstein (1987) show that the first best is attained if the agent's private information is perfectly revealed ex post with some positive probability. Using a sufficiently severe punishment whenever he did not report his type truthfully, the fear of being caught then prevents an agent from being untruthful, and the efficient allocation can be implemented. Subsequently, it was shown that even very uninformative signals are sufficient to eliminate the agent's rent and to ensure the first-best outcome, provided the signal can be contractually employed, the agent is risk neutral and can be subjected to unboundedly high penalties (Crémer and McLean, 1988; Riordan and Sappington, 1988).[6] This is because even if the signal is very inaccurate or rarely available, the principal can use larger penalties to compensate for the reduced informational

[5] Importantly, this occurs even though we ignore any commitment problems. It is well known that additional information can be harmful if commitment not to use the information is ruled out (Riordan, 1990; Crémer, 1995; Dewatripont and Maskin, 1995). Upward distortions are also known from the literature on countervailing incentives where the agent's reservation utility is type dependent. See Lewis and Sappington (1989) and Jullien (2000) for further references.

[6] General conditions on the distribution of signals for which this result holds are derived by Riordan and Sappington (1988) for the standard agency model and by Crémer and McLean (1988) for auctions. See also McAfee and Reny (1992) for an extension beyond the auction setting.

content, which again slackens the incentive-compatibility constraints to the point where rents are zero.[7]

Since arbitrarily high punishments seem rather unrealistic, the more recent literature has studied whether the favorable effect of additional information is preserved when the agent cannot be held unboundedly liable. To our knowledge these papers exclusively restrict attention to a setting in which the agent's utility is decreasing in the induced action, i.e., where he is in a "seller" position in our terminology. Two basic forms of limited liability can be distinguished. First, one can interpret limited liability as a bound on the maximum punishment that can be imposed on an agent. In this interpretation, the punishment is exogenous as it does not vary with the specifics of the contract. Second, one can interpret limited liability as an exogenous upper bound on the agent's total payments to the principal.[8] The maximum punishment then endogenously depends on the contractual provisions, in particular, on the contractual payments that are made to or from the agent as a compensation for the transaction.[9]

Considering exogenous punishments, Kofman and Lawarrée (1993) show that the optimal contract does depend on the accuracy of the signal in the following way: If the signal is imprecise, it leaves the optimal action of low-type agents unaffected while reducing the informational rent of the better type (see also Baron and Besanko, 1984). This is because with an exogenous punishment level, a more precise signal in this interval reduces the absolute informational rent, but not the marginal informational rent of good-type agents. Accordingly, the second-best distortion of the standard contract remains optimal. Once one arrives at a precision level where the information rent is completely eliminated, a better signal precision now leads the principal to reduce the allocative distortion, that is, the equilibrium action of the low-type agent is raised relative to the second best. Finally, when the allocation becomes first best, the principal starts to reduce the frequency of the signal while leaving the first-best allocative outcome. The Kofman and Lawarrée results show that for exogenous punishments, informative signals—at least weakly—raise the level of allocative efficiency, and at the same time lower the agent's information rents.

The effect of ex post signals in settings with endogenous punishments has been studied in Laffont and Tirole (1993, chapter 12) and in Demougin and Garvie (1991).[10] In the model analyzed by Laffont and Tirole, the signal is perfectly

[7] Note that in contrast to the case of perfect signals, penalties are realized in equilibrium as low-quality agents are also subjected to these penalties with positive probabilities in equilibrium. This explains why an inaccurate signal does not facilitate an efficient outcome when the agent is risk averse.

[8] An alternative way to model endogenous punishments would be to require that the agent's total utility—instead of his total payments—cannot fall below a certain boundary level. The problem of this approach is that an agent's utility depends on his true type that is unobservable. Consequently, the maximum feasible penalty need not be well defined off equilibrium.

[9] A textbook discussion of the distinction can be found in Laffont and Martimort (2001). The exogenous penalty interpretation has been employed, e.g., in Baron and Besanko (1984) and Kofman and Lawarrée (1993). That the principal is unable to extract money from the agent is assumed in Sappington (1983), Border and Sobel (1987), and Melumad and Mookherjee (1989), among others.

[10] See also Gary-Bobo and Spiegel (2003) for a model in which additional signals represent real cost shocks, that is, where a signal has a direct allocative effect. Khalil (1997) analyzes a setting in which the principal cannot commit to costly auditing. He finds that whenever auditing occurs with positive

revealing but observed only with a certain probability. This situation is qualitatively identical to the situation we study, where a less than perfectly accurate signal is always available. The authors argue that monitoring again reduces the agent's rent and mitigates the downward distortion. However, we will see below that the efficiency-improving effect arises only because Laffont and Tirole impose an upper bound on level of signal precision. If one allows for more informative signals, our results indicate that additional ex post information can again render it optimal to raise output above the first-best level, so that total surplus is reduced. Finally, Demougin and Garvie (1991) analyze a framework that is closely related to our model. In a setting with a continuous type space and an agent utility linear in the outcome, this article concludes that a more informative signal always reduces informational rents, mitigates the distortions, and is thus welfare improving. Although contradictory at first sight, their result is consistent with the findings laid out above as we will see below. In particular, their model may be seen as a special case of ours (but with a continuous type space) with specifications of the agent's utility function ensuring that neither of the counterintuitive results we identify can occur.

3. THE MODEL

Consider the following generic version of a principal–agent model with adverse selection. The utility functions of the principal (P) and the agent (A) are, respectively, $u_P = v(x, \theta) - t$ and $u_A = u(x, \theta) + t$, where $x \in [\underline{x}, \bar{x}] \subset \mathbb{R}$ is a contractible action, θ is a random parameter, and $t \in \mathbb{R}$ is a (possibly negative) transfer payment from P to A. The parameter θ is private information to the agent and can take only two values, $\theta \in \{\theta_h, \theta_l\}$.[11] The ex ante probability that $\theta = \theta_h$ is common knowledge and denoted by $q \in (0, 1)$.

To fix ideas, it will be helpful in what follows to keep in mind two applications of the above model that have been extensively studied in the literature. The first example is a vertical relationship between an upstream firm (a manufacturer) and a downstream firm (a retailer), where the principal is the monopolistic supplier who sells a quantity x of some good or service to the agent at cost $-v(x, \theta) \equiv c(x) \geq 0$. The retailer's gross profit is $u(x, \theta) \geq 0$. It depends on his intrinsic preference parameter θ (e.g., downstream market characteristics) and is strictly increasing in the quantity bought; i.e., $u'(x, \theta) > 0$, primes denoting partial derivatives with respect to x. The second example is a procurement situation where the principal is a buyer who orders some product or service of noncontractible quality. The quality that is delivered depends on the seller's intrinsic type, which may reflect his technological know-how or his craftsmanship, and the high-quality agent may

probability, the agent receives no rent, and there is an upward distortion that increases the probability that the agent complies with the contract. The driving force behind this result is that the principal must be given sufficient incentives to audit. Although the mechanism at work is thus different, it also requires transfer-dependent penalties.

[11] The subscript h indicates a "high type" and the subscript l a "low type." Note that the label "high type" ("low type") refers to an agent with a *high* (low) valuation for a good or service if he is a buyer, and to an agent with *low* (high) production costs if he is a seller.

incur higher production costs (he uses more expensive inputs). The buyer's utility from ordering x units is then $v(x, \theta) \geq 0$, and the supplier's production cost is $-u(x, \theta) = c(x, \theta) \geq 0$. Total costs strictly increase in the quantity supplied, i.e., $u'(x, \theta) < 0$, and in the quality parameter θ.

Although the principal does not observe θ directly, she has access to a verifiable signal $s \in \{s_h, s_l\}$, which is realized after the action x has been taken, and which is imperfectly correlated with θ. In the manufacturer-retail example, s could be the final price that can be charged by the retailer as an intermediate on the downstream market.[12] In the trade-quality example, the signal s could be a malfunctioning of the product or some other verifiable indicator that the trade/service was not of acceptable quality. In both cases, the quality of information is related to the agent's cost parameter that the principal can infer from the characteristics of the finished product or obtain through conducting audits. Let π_{ij} be the probability that the signal $s = s_i$ is realized, conditional upon a parameter value $\theta = \theta_j, i, j \in \{h, l\}$ and assume $\pi_{ll} = \pi_{hh} \equiv \pi$ for simplicity. Hence, the signal is "correct" with probability π and "incorrect" with probability $1 - \pi$. In what follows, we use π as a measure of the informativeness of the signal s and without loss of generality let $\pi > 1/2$.

ASSUMPTION 1. *The functions* $v(\cdot)$ and $u(\cdot)$ *are twice continuously differentiable, monotone, and concave in x. Total surplus* $S(x, \theta_i) \equiv v(x, \theta_i) + u(x, \theta_i)$ *is strictly concave in x. Furthermore*,

(a) $u(x, \theta_h) > u(x, \theta_l)\ \forall x \in (\underline{x}, \bar{x}]$,
(b) $u'(x, \theta_h) > u'(x, \theta_l)\ \forall x \in [\underline{x}, \bar{x}]$,
(c) $x_i^{\mathrm{FB}} = \arg\max S(x, \theta_i)$ *satisfies* $x_l^{\mathrm{FB}} \leq x_h^{\mathrm{FB}}$ *and* $x_i^{\mathrm{FB}} \in (\underline{x}, \bar{x}), i \in \{l, h\}$,
(d) $\hat{x}_l(\pi) = \arg\max S(x, \theta_l) - \frac{q}{1-q}[u(x, \theta_h) - \frac{1-\pi}{\pi} u(x, \theta_l)]$ *is unique and satisfies* $\hat{x}_l(\pi) \in (\underline{x}, \bar{x})$ *for all values* $\pi \in [\frac{1}{2}, 1)$.

Assumptions 1 (a) and (b) state that the agent's possible types θ have a natural ordering both in absolute and marginal utilities (single crossing property). Parts (c) and (d) will prove helpful in characterizing and deriving the comparative static properties of optimal contracts because they allow us to confine attention to interior optima. This is ensured by Assumption 1 (c) for the first-best contract (under perfect information). Similarly, Assumption 1 (d) ensures that the second-best contract (with imperfectly informative signal) for a θ_l-type agent can be characterized in terms of a first-order condition. This will allow us to

[12] Royalties to be paid by coal mining companies for operating on publicly owned land will generally vary with the price of coal from the same general area, its quality, and other factors the commissioner in charge deems "relevant" (see, e.g., the Alaska Administrative Code). More generally, contracts between a manufacturer and its exclusive retailers are often contingent on the retailers' behavior that supplements the information contained in the sales data (Lafontaine and Slade, 1996). In franchising relationships, for instance, the franchisor usually takes the right to terminate the contract at will if the franchisee is not maintaining quality standards (which is subject to random monitoring). Since franchise contracts typically require franchisees to make highly specific investments in equipment, these investments are (at least partially) lost when the franchisor receives a bad signal (Dnes, 1996).

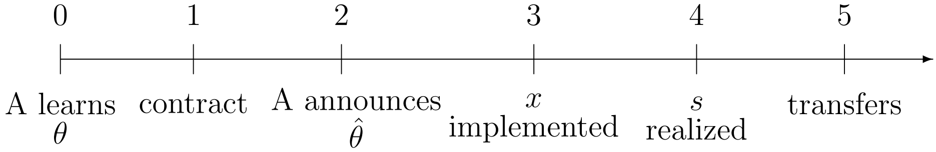

FIGURE 1

THE SEQUENCE OF EVENTS

conduct comparative static exercises with respect to the signal precision as well as to compare second-best and first-best solutions.[13]

The timing is as follows. Before contracting takes place, nature chooses θ and the agent learns his type. Then, the principal proposes a contract to the agent, which the latter can accept or reject. Focusing on the most interesting case, we assume throughout that the principal wants to contract with both types. If the agent accepts, the action x is taken in accordance with the contract. Next, the signal s is realized and the contractually specified transfer is paid. If the agent rejects, the parties obtain their reservation utilities. The sequence of events is summarized in Figure 1.

Assuming the principal can commit herself not to renegotiate the contract, we can invoke the Revelation Principle and confine attention to contracts $\{x(\hat{\theta}), t(\hat{\theta}, s)\}$, which specify an action x and a transfer t as a function of the agent's report $\hat{\theta}$ and the realization of the signal s. As future points of reference, we first characterize the cases where information is symmetric and where the signal is not available, respectively.

3.1. *First Best.* If θ is publicly observable, the principal maximizes her utility, $u_P = v(x, \theta_i) - t$, subject to the agent's participation constraint $u_A = u(x, \theta_i) + t \geq \bar{u}$, where $\bar{u}$ denotes his reservation utility. For a type-θ_i agent, the first-best action is uniquely characterized by $S'(x_i^{FB}, \theta_i) = 0$ and the transfer payment is $t_i^{FB} = \bar{u} - u(x_i^{FB}, \theta_i)$.

3.2. *Second Best.* Next, suppose θ is known only to the agent but the signal is not available or, equivalently, completely uninformative ($\pi = 1/2$). Let (x_i, t_i) denote the contract designed for an agent who claims to be of type θ_i. The individual rationality constraints are

$$u(x_i, \theta_i) + t_i \geq \bar{u} \qquad i \in \{l, h\} \tag{1}$$

In addition, truthful revelation requires

$$u(x_i, \theta_i) + t_i \geq u(x_j, \theta_i) + t_j \qquad i, j \in \{l, h\},\ i \neq j \tag{2}$$

[13] Note that $x_l^{FB} \leq x_h^{FB}$ is already implied by the single crossing property if the principal's utility $v(\cdot)$ does not depend on θ (otherwise, $v'(x, \theta)$ increasing in θ is a sufficient condition). Also observe that for any given $q \in (0, 1)$ the objective function in Assumption 1 (d) is concave if $v(\cdot)$ is sufficiently concave. Moreover, it is sufficient for our analysis that Assumption 1 (d) is satisfied for $\pi \leq \pi^{FB}$, which is defined below.

The principal maximizes her expected utility $q[v(x_h, \theta_h) - t_h] + (1-q)[v(x_l, \theta_l) - t_l]$, subject to (1) and (2). It is easy to see that the incentive constraint for the low-type agent as well as the individual rationality constraint for the high-type agent are slack at the optimum and can be ignored. From the first-order conditions, the second-best actions are determined by

$$S'\left(x_h^{\mathrm{SB}}, \theta_h\right) = 0 \qquad \Rightarrow \qquad x_h^{\mathrm{SB}} = x_h^{\mathrm{FB}} \quad \text{and}$$
$$S'\left(x_l^{\mathrm{SB}}, \theta_l\right) = \frac{q}{1-q}\phi'\left(x_l^{\mathrm{SB}}\right) \qquad \Rightarrow \qquad x_l^{\mathrm{SB}} < x_l^{\mathrm{FB}}$$

where $\phi(x) \equiv u(x, \theta_h) - u(x, \theta_l) > 0$ with $\phi' > 0$. The corresponding transfers are $t_l^{\mathrm{SB}} = \bar{u} - u(x_l^{\mathrm{SB}}, \theta_l)$ and $t_h^{\mathrm{SB}} = \bar{u} - u(x_h^{\mathrm{FB}}, \theta_h) + \phi(x_l^{\mathrm{SB}})$. Hence, under the no-signal second-best contract, the action of the high-type agent is first best and he earns an informational rent equal to $\phi(x_l^{\mathrm{SB}})$. In contrast, the action of a low-type agent is distorted downward and he obtains his reservation utility. Evidently, this result does not depend on whether the agent is a buyer or a seller, i.e., if his payoff is increasing or decreasing in x.[14]

4. OPTIMAL CONTRACTING WITH A VERIFIABLE SIGNAL

We now turn to the case in which the principal can condition the transfers specified in the contract on the verifiable (and informative) signal s. Clearly, she may now want to reduce the transfer whenever the realization of s contains evidence contradicting the agent's claim $\hat{\theta}$. For illustrational purposes, let us first assume that the agent disposes of unlimited wealth so that the size of possible penalties is unbounded. In this situation, the agent's rent as well as the distortion identified in the last section disappear. This can be seen by the following argument, which goes back to Nalebuff and Scharfstein (1987).[15] Note first that given the distribution of the signal as described above we can rewrite the incentive constraint of the high-type agent and the individual rationality constraint of the low-type agent as

$$(\mathrm{IC}_h) \qquad u(x_h, \theta_h) + t_h \geq u(x_l, \theta_h) + (1-\pi)t_l(s_l) + \pi t_l(s_h)$$

and

$$(\mathrm{IR}_l) \qquad u(x_l, \theta_l) + \pi t_l(s_l) + (1-\pi)t_l(s_h) \geq \bar{u}$$

If the signal was completely uninformative, $\pi = 1/2$, a binding (IR_l) would require $dt_l(s_l)/dt_l(s_h) = -1$, i.e., any reduction in $t_l(s_h)$ must be accompanied by an identical raise in $t_l(s_l)$. By inspection, the availability of the signal then leaves (IC_h)

[14] Note, though, that the conclusion is a matter of convention given the properties of the underlying problem as summarized in Assumption 1. For instance, we could use the transformation $y := \bar{x} - x$, which reversed the single crossing property. The optimal contract would then specify $y_l^{\mathrm{SB}} > y_l^{\mathrm{FB}}$ and our results in the remainder of the article would change accordingly.

[15] In their original work, the signal is perfect but it is attained with less than full probability.

unaffected, implying there is no gain in using the signal in a contractual agreement. A different picture emerges if $\pi > 1/2$, however. Now, $dt_l(s_l)/dt_l(s_h) = -(1-\pi)/\pi > -1$, i.e., lowering $t_l(s_h)$ no longer requires an equal size increase in $t_l(s_l)$ in order to keep (IR$_l$) satisfied. But any decrease in $t_l(s_h)$ that is accompanied by some smaller increase in $t_l(s_l)$ relaxes the θ_h-type agent's incentive constraint (the right-hand side of (IC$_h$) becomes smaller). This is because once the signal is informative, a θ_h-agent who was untruthful faces a different distribution over signals and, hence, transfers, as a truthful θ_l agent. There must then exist some transfer $t_l(s_h)$ and a corresponding transfer $t_l(s_l)$ such that (a) (IR$_l$) is satisfied with equality and (b) (IC$_h$) is slack for *any* choice of x_l. In other words, it becomes possible to implement the efficient allocation x_l^* without any need to concede a costly informational rent to the high-type agent. Penalizing an agent who claimed to be of low type for contradictory evidence is sufficient to implement the first best, even if this information is very inaccurate. However, it is easily seen that the effective penalty, which is equal to $(\pi - 1/2)t_l(s_h)$, must converge to infinity as π converges to 1/2, i.e., it must increase without bounds as the signal becomes less and less informative.

In the remainder, we rule out arbitrarily high punishments by imposing the following assumption:

ASSUMPTION 2. *The agent is protected by limited liability,*

$$(\text{LL}_{ij}) \qquad t_i(s_j) \geq -W \qquad \forall\, i, j \in \{l, h\}$$

Furthermore,

$$(3) \qquad \bar{u} + W \geq \max\left\{u\left(x_h^{\text{FB}}, \theta_h\right), u\left(x_l^{\text{SB}}, \theta_l\right), u\left(x_l^{\text{FB}}, \theta_h\right)\right\}$$

The first part of Assumption 2 imposes an exogenous lower bound on the feasible transfers between principal and agent, which we assume to be commonly known.[16] We can interpret (LL$_{ij}$) as a wealth constraint where $W \geq 0$ denotes the initial wealth of the agent. Since this constraint restricts the total payments that an agent can make to the principal, the maximum feasible punishment depends on the size of transaction payments specified in a mechanism and is thus endogenous. Note that similar limits on transfers would arise from legal restrictions such as minimum wage laws (in which case $-W \geq 0$ is the minimum wage) or if the agent's preferences exhibit infinite risk aversion below a certain transfer level.

The second part of Assumption 2 ensures that the limited liability constraints do not bind at the first- and second-best benchmark solutions determined previously, so that those optimal contracts are unaffected by (LL$_{ij}$).[17] The assumption serves to establish two benchmark outcomes that will be used for comparison with our

[16] For an analysis of situations in which the agent alone knows W, see Lewis and Sappington (2000, 2001). The relevance of limited liability constraints has long been stressed in the literature on moral hazard (see, e.g., Sappington, 1983, on hidden information and Brander and Spencer, 1989, on hidden action).

[17] An assumption on $\bar{u} + W \geq u(x_h^{\text{SB}}, \theta_h)$ is redundant because a θ_h-type agent earns an informational rent under asymmetric information, implying $t_h^{\text{SB}} < t_h^{\text{FB}}$.

subsequent results. Note that if the agent's reservation utility $\bar{u}$ is equal to zero, (3) is trivially satisfied if the agent is in a seller position as in our procurement example: Even for $W = 0$, the first-best and second-best solutions remain feasible because the agent receives a positive payment under the optimal contract. This is not true if the agent is in a buyer position as in our monopolistic seller example. Then, the principal will sell to the agent only if she receives a positive payment, which requires a positive endowment $W > 0$. Assumption 2 also allows us to focus attention on the interesting case in which the agent's liability is large enough for the first best to be implementable at $\pi = 1$, i.e., if the agent's type is perfectly revealed ex post.[18]

With the ex post signal, the agent's participation constraints are

$$(\text{IR}_i) \qquad \pi t_i(s_i) + (1-\pi)t_i(s_j) + u(x_i, \theta_i) \geq \bar{u} \quad i, j \in \{l, h\},\ i \neq j$$

In addition, incentive compatibility now reads for $i, j \in \{l, h\}$, $i \neq j$,

$$(\text{IC}_i) \quad \pi t_i(s_i) + (1-\pi)t_i(s_j) + u(x_i, \theta_i) \geq \pi t_j(s_i) + (1-\pi)t_j(s_j) + u(x_j, \theta_i)$$

The principal's problem is to choose $\{x_i, t_i\,(s_j)\}$ so as to

$$(\text{P}) \qquad \begin{aligned} \text{maximize} \quad & q[v(x_h, \theta_h) - \pi t_h(s_h) - (1-\pi)t_h(s_l)] \\ & + (1-q)[v(x_l, \theta_l) - \pi t_l(s_l) - (1-\pi)t_l(s_h)] \\ & \text{s.t. } (\text{IR}_i), (\text{IC}_i), \text{ and } (\text{LL}_{ij}) \end{aligned}$$

As can easily be seen, the principal's return from the relationship is now strictly higher than under the optimal second-best contract in which no informative signal is available. Also, if the signal is sufficiently precise, the possibility of contracting on s enables her to implement the first best. The relevant cutoff value is given by (see the Appendix)

$$\pi^{\text{FB}} \equiv \frac{\bar{u} + W - u\big(x_l^{\text{FB}}, \theta_l\big)}{2\big[\bar{u} + W - u\big(x_l^{\text{FB}}, \theta_l\big)\big] - \phi\big(x_l^{\text{FB}}\big)} \in \left(\frac{1}{2}, 1\right)$$

In the following, we first focus our investigation on how additional ex post information affects the feature of the optimal contract that concerns the induced action x, turning to the question of informational rents later. As the effect on the efficiency of the contractually induced allocation will crucially depend on whether the agent's utility is increasing or decreasing in x, we consider each of these two possibilities in turn.

Let us start with a situation in which the agent is in a "buyer" position. As an application, recall our first example with the principal as a monopolistic seller

[18] To see this, suppose $\pi = 1$ and consider the first-best contract with the transfer equal to $-W$ in case the agent did not tell the truth. Under Assumption 2, this contract is incentive compatible because $\bar{u} \geq u(x_l^{\text{FB}}, \theta_h) - W$ and $\bar{u} \geq u(x_h^{\text{FB}}, \theta_l) - W$.

who supplies the agent as the owner or manager of a retail store. The profitability of the store depends on the agent's sales skills, which is his private knowledge, with θ_h indicating an agent with high skills. In this case, the agent's gross expected profit or utility $u(\cdot)$ is increasing in x and the principal can make the transfer payment (the price charged, the license fee, or a royalty) dependent on an ex post available signal that is related to the retailer's productivity. This signal may be the retailer's realized profit, which is a stochastic indicator for his unknown type. Some other prominent applications of adverse selection that have been studied in the literature and in which the agent is in a "buyer" position are loan contracting (the agent is granted a credit of size x by the principal and the signal is the agent's default) and environmental regulation (the agent prefers to produce more output x, which is harmful for the environment and the signal is an abatement cost estimate generated by an audit).

PROPOSITION 1. *Suppose $u(x, \theta_i)$ is a monotonically increasing function of x. Under the optimal contract with a verifiable ex post signal, the action taken by the low-type agent, x_l^S, is continuous in the informativeness π of the signal and efficient for $\pi \geq \pi^{\text{FB}}$. Otherwise, we have $x_l^S \leq x_l^{\text{FB}}$ and there exists a value $\underline{\pi} \in (1/2, \pi^{\text{FB}})$ such that*

$$\pi < \underline{\pi} \;\Leftrightarrow\; x_l^S < x_l^{\text{SB}}$$

The action taken by the high-type agent is efficient, i.e., $x_h^S = x_h^{\text{FB}}$ irrespective of π.

The main result of Proposition 1 is illustrated in Figure 2, which depicts the equilibrium action in state θ_l as a function of the precision of the signal, π.

We see that the induced distortions are alleviated relative to a situation in which no signal is available *only if* the ex post signal is sufficiently precise. In

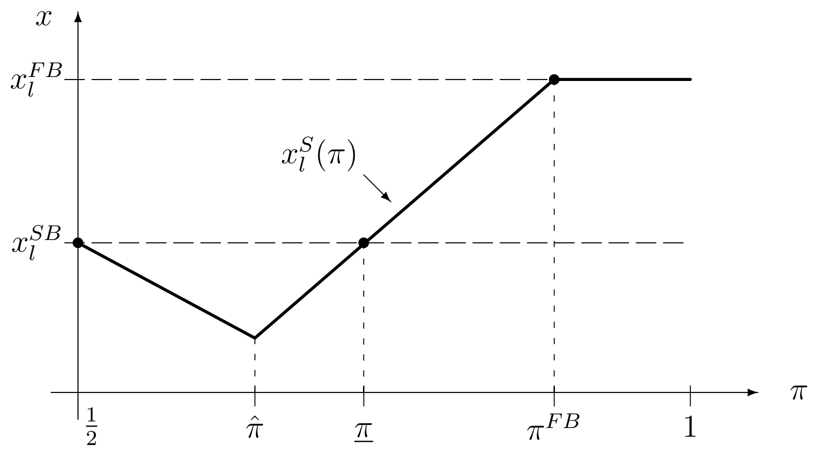

FIGURE 2

THE AGENT IS IN A "BUYER" POSITION

particular, additional information reinforces the inefficiency whenever $\pi < \underline{\pi}$, so that the total surplus continues to fall over this range as the signal becomes more and more informative. This finding seems to lack intuition at first glance; after all, we know that the optimal contract balances the principal's concern for surplus maximization with her desire to extract rents. Since an informative signal alleviates the latter problem, the extent of this trade-off should change in favor of surplus maximization. This intuition is flawed, however, because it ignores the fact that additional information may be used most effectively to reduce the agent's rent by introducing further distortions. To see this more clearly, recall from the second-best benchmark that for an uninformative signal with $\pi = 1/2$ only (IR_l) and (IC_h) bind and the informational rent is strictly positive. For π not too large, this will continue to be the case and we can use (IR_l) and (IC_h) to write the informational rent of a high-type agent as

$$
\begin{aligned}
(4) \qquad R(x_l, \pi) &= u(x_h, \theta_h) + \pi t_h(s_h) + (1-\pi)t_h(s_l) - \bar{u} \\
&= [u(x_l, \theta_h) + \pi t_l(s_h) + (1-\pi)t_l(s_l)] \\
&\quad - [u(x_l, \theta_l) + \pi t_l(s_l) + (1-\pi)t_l(s_h)] \\
&= \phi(x_l) - (2\pi - 1)\big[t_l(s_l) - t_l(s_h)\big]
\end{aligned}
$$

where $\phi(x_l) = R(x_l, 1/2)$ is the corresponding rent in the no-signal case. The last term on the right-hand side of (4) reflects the fact that a dishonest high-type agent faces a different probability distribution of the signal than a truthful low-type agent. In particular, since the probability of a signal $s = s_h$ is higher for the former, it is optimal for the principal to set the agent's compensation in case of contradicting evidence as low as possible. Hence, we must have $t_l(s_h) = -W$ and (4) becomes

$$(5) \qquad R(x_l, \pi) = \phi(x_l) - (2\pi - 1)\,[t_l(s_l) + W]$$

The term in square brackets is the net expected punishment inflicted on an agent who untruthfully claims to be of type θ_l. It consists of the difference between the transfer $t_l(s_l)$ that the agent receives if the signal falsely indicates that he was honest and the minimum transfer when the signal (correctly) indicates noncompliance, $t_l(s_h) = -W$. If the transfer payment is negative, as would be the case in a vertical (or credit) relationship with the agent buying (or borrowing) from the principal, we have $-t_l(s_h) = W > -t_l(s_l) > 0$.[19] Inspection of (5) reveals that, in order to reduce the rent, the principal will want to raise the payment $t_l(s_l)$ in comparison to the no-signal case. What does increasing $t_l(s_l)$ mean in terms of the action x_l? From (IR_l), we have

$$(6) \qquad t_l(s_l) = [\bar{u} - u(x_l, \theta_l) + (1-\pi)W]/\pi$$

[19] Note that the first inequality is a consequence of Assumption 2.

i.e., $u'(x, \theta) > 0$ implies that $t_l(s_l)$ decreases in x_l. Hence, a *reduction* in x_l diminishes the agent's rent relative to the no-signal second-best case by the above argument. In our monopolistic supplier example, the smaller the quantity purchased from the principal, the lower the price a truthful agent has to pay, and the more money is left in the pocket of an untruthful agent that can serve as a penalty if the signal indicates noncompliance.

Consequently, the availability of additional information through s aggravates the welfare reduction caused by the downward distortion of x_l, provided π is relatively small. Indeed, this effect becomes stronger the more precise the signal is for values $\pi \leq \hat{\pi}$; formally, the principal's marginal benefit from reducing x_l, $R'(x_l, \pi) = \phi'(x_l) + ((2\pi - 1)/\pi)u'(x_l, \theta_l)$, is increasing in π. At $\hat{\pi}$, the agent's rent drops to zero and (IR_h) becomes binding. Then, the above effect is no longer operative and the principal optimally increases x_l until the (IC_h) constraint becomes slack at $\pi = \pi^{\text{FB}}$.

Next, we turn to the case where the agent is in a "seller" position. In our procurement example, the agent is a seller who delivers goods or services of unknown quality to the principal as his customer. The quality is private knowledge of the agent with the index l referring to an agent of high quality and production cost. In this case, the agent's utility (cost) is decreasing (increasing) in x and the principal can make the transfer (the agent's compensation for the service rendered or the price of the goods delivered) dependent on a signal that is related to his quality/production cost. This signal may be a malfunctioning of the product or any other stochastic quality indicator. For example, the car may break down shortly after a mechanic (the agent) repaired it and the penalty is simply a warranty. The case where the agent is in a seller position also applies to a variant of the adverse selection model that includes unobservable effort and has been studied extensively in the literature.[20] Some well-known applications of this framework are the regulation of a firm with unknown cost as formalized by Laffont and Tirole (1993), or the manager–shareholder model by Kofman and Lawarrée (1993). In both models, additional ex post information will naturally be available whenever the principal (regulatory agency or shareholder) conducts audits.

Let

$$\bar{\pi} \equiv \frac{u'\left(x_l^{\text{FB}}, \theta_l\right)}{u'\left(x_l^{\text{FB}}, \theta_l\right) + u'\left(x_l^{\text{FB}}, \theta_h\right)} \in \left(\frac{1}{2}, 1\right)$$

PROPOSITION 2. *Suppose $u(x, \theta_i)$ is a monotonically decreasing function of x. Under the optimal contract with a verifiable ex post signal, the low-type agent's action x_l^S is continuous in π and efficient for $\pi \geq \pi^{\text{FB}}$. Otherwise, $x_l^S \geq x_l^{\text{SB}}$ and*

(a) if $\bar{\pi} \geq \pi^{\text{FB}}$, we have $x_l^S < x_l^{\text{FB}}$ for all values $\pi \geq 1/2$;
(b) if $\bar{\pi} < \pi^{\text{FB}}$, we have $x_l^S > x_l^{\text{FB}} \Leftrightarrow \pi > \bar{\pi}$.

[20] For example, we could have $x = \theta + e$ where x is an output or cost-related variable and e the effort exerted by the agent. Effort is costly, so that the agent's utility can be written as $u_A = -C(e) + t = t - C(x - \theta)$ with $u'(x, \theta) = -C_e < 0$.

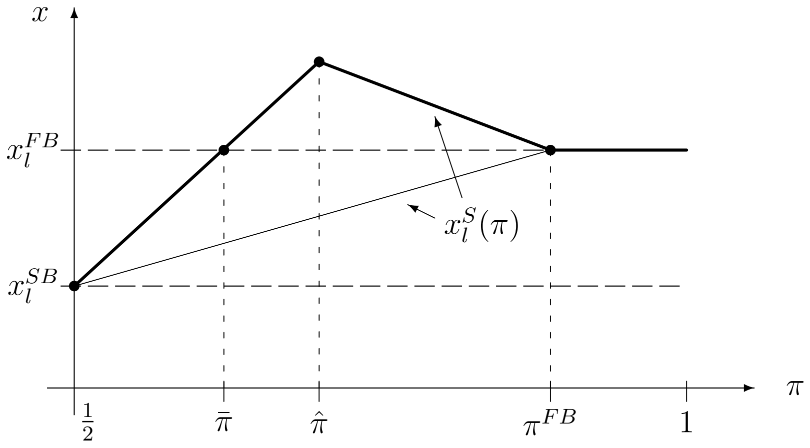

FIGURE 3

THE AGENT IS IN A "SELLER" POSITION

The action taken by the high-type agent is efficient, i.e., $x_h^S = x_h^{\text{FB}}$ irrespective of π.

Again, the content of this proposition is best illustrated graphically. This is done in Figure 3, which displays x_l^S as a function of π.

According to the proposition, two possibilities have to be distinguished. First, if $\bar{\pi} \geq \pi^{\text{FB}}$, the downward distortion of x_l is simply alleviated so that total welfare increases as additional ex post information is present; i.e., the more precise the signal, the smaller is the distortion, as has been suggested by the literature discussed in Section 2. This is case (a), as indicated by the thin line. Importantly, case (a) always applies if $\bar{u} = W = 0$ and $u(x, \theta) = -x\theta$, implying $\bar{\pi} = \pi^{\text{FB}}$ from the definitions of $\bar{\pi}$ and π^{FB}. This particular specification, which is completely innocuous in the standard model without ex post information, has been used in Demougin and Garvie (1991) as well as in Khalil (1997). Both papers, therefore, correctly conclude that a transfer-dependent penalty by itself does not generate overproduction and the well-known result of downward distorted production continues to hold.[21] However, $\bar{\pi} < \pi^{\text{FB}}$ is easily possible if u is strictly concave (see the Appendix for a simple example) or if $W > 0$. This is case (b), which is depicted by the thick line in the figure. If $\bar{\pi} < \pi^{\text{FB}}$, the availability of noisy ex post information on the agent's type will lead the principal to distort x_l in the *opposite* direction. To see why, recall that the informational rent of the high-type agent is given by (5), provided R is strictly positive. As before, we have $t_l\,(s_h) = -W$ and the principal wants to raise $t_l(s_l)$ above the amount that is optimal in the no-signal case in order to reduce

[21] For a model in which overproduction may occur despite the normalization $\bar{u} = W = 0$, see Khalil and Lawarrée (2001). This article examines a very different framework in which the principal ex post chooses between input and output monitoring, thereby taking advantage of the possibility that the agent can be caught "on the wrong foot."

the rent. In contrast to the previous case, however, $t_l(s_l)$ is now increasing in x_l due to $u'(x, \theta) < 0$ (see Equation (6)). In our trade-quality example, the more a high-cost/high-quality agent is to produce, the more he receives in compensation and the more severely an untruthful agent can be punished if the signal indicates low quality. Note that such a penalty has the natural interpretation of a warranty that covers malfunctioning (a signal indicating low quality and thus low costs).[22]

Therefore, the high-cost seller's output x_l always unambiguously exceeds x_l^{SB}, regardless of whether we are in case (a) or case (b). Also, as long as π is sufficiently small, the effect again becomes stronger the more informative the signal is; formally, $R'(x_l, \pi)$ is now decreasing in π. But since the driving force behind raising x_l is the *marginal*—instead of the absolute—effect on the agent's rent, the effect may even lead the principal to raise x_l above x_l^{FB}.[23] Specifically, this situation emerges if the marginal effect on $-u(x_l^{FB}, \theta_l)$ and, hence, on $t_l(s_l)$ is sufficiently stronger than the marginal effect on $\phi(x_l^{FB}) = u(x_l^{FB}, \theta_h) - u(x_l^{FB}, \theta_l)$, i.e., for $\bar{\pi} < \pi^{FB}$. Again, if the agent's rent R drops to zero and (IR_h) becomes binding at $\hat{\pi}$, this effect vanishes. For high values of π, the (downward or upward) distortion is thus alleviated and eventually, the first best is implemented for $\pi \geq \pi^{FB}$.

Having analyzed the allocative consequences of additional information for the two cases of a buyer-agent and a seller-agent, respectively, we can now explore how individual payoffs will be affected. Clearly, the principal's expected return never falls as an informative signal becomes available: Because she could always offer the optimal second-best contract that does not condition on the signal, this observation follows trivially from revealed preferences. In light of the previous results, however, it is not a priori obvious how the agent's informational rent $R(x_l^S, \pi)$ is affected by additional ex post information.

COROLLARY 1. *If $u'(x, \theta_i) > 0$, $R(x_l^S, \pi)$ is weakly decreasing in the precision of the signal, π. If $u'(x, \theta_i) < 0$, $R(x_l^S, \pi)$ weakly decreases in π for all values $\pi \geq \bar{\pi}$, but it may increase in π for values $\pi < \bar{\pi}$. In particular, we may have $R(x_l^S, \pi) > R(x_l^{SB}, 1/2) = \phi(x_l^{SB})$ for some $\pi \in (1/2, \bar{\pi})$.*

The first part of the corollary is straightforward. Consider Figure 2 in which the agent is in a buyer position and $u'(x, \theta_i) > 0$. For values of $\pi < \hat{\pi}$, the distortion of x_l is aggravated and the total surplus decreases in π. Hence, the agent cannot be better off if additional ex post information about him becomes available. For

[22] See Emons (1989) for a survey of warranty contracts and the rationales behind them. A slightly different formulation of the problem would also allow the penalty to be interpreted as a money-back guarantee (with $W = 0$).

[23] This result should be contrasted to Laffont and Tirole (1993, chapter 12), who conclude that "monitoring of effort ... consequently leads to a smaller distortion of effort for the inefficient type" (p. 529). In their model, monitoring generates a signal that is perfectly revealing but observed with less than full probability, $z < 1$. The authors implicitly assume that (i) the agent cannot be punished if no signal has been observed (no evidence and favorable evidence cannot be distinguished) and that (ii) z is smaller than some threshold value z^* (which corresponds to $\bar{\pi}$ in our context). If one maintains (i) but allows for signal frequencies $z > z^*$, a positive output distortion would emerge for the same reason as in our model. Also, if assumption (i) is abolished, it is easy to see that the first best can be achieved in their framework.

$\pi \geq \hat{\pi}$, his rent is zero, so that a more precise ex post signal cannot help him either. But a similar reasoning need not apply for an agent in a seller position where $u'(x, \theta_i) < 0$: As is indicated in the second part of the corollary, the agent may actually *benefit* from an observable ex post signal about his type. From Figure 3, we see that the informational rent can only decrease for values $\pi \geq \bar{\pi}$. In case (a), the seller-agent earns no rent for those values of π. In case (b), x_l increases above x_l^{FB}, so that the total surplus again decreases (if $\pi \leq \hat{\pi}$) or the agent's rent is again zero (if $\pi > \hat{\pi}$). However, if $\pi < \bar{\pi}$ more precise ex post information reduces the distortion, so that total surplus increases. Then, not only the principal's profit, but also the agent's rent can increase. In particular, one can easily construct examples in which the negative effect on $R(\cdot)$ due to a more precise signal is overcompensated by the positive effect on $R(\cdot)$ caused through the corresponding raise in x_l.[24] In our trade-quality scenario, for example, this result implies that the agent as the seller may actually gain from a warranty contract that becomes feasible if the buyer can condition payments on product performance.

5. DISCUSSION AND CONCLUDING REMARKS

In this article, we have studied a straightforward variant of a simple principal–agent adverse selection problem in which information that is imperfectly correlated with the agent's type becomes public ex post. Because the agent was protected by limited liability, the principal could not implement the first-best allocation when the ex post signal was not sufficiently accurate, which is in line with previous findings. The main results of our article, though, contrast sharply with the previous literature. Perhaps most importantly, we have shown that the expected surplus from the agency relationship need not increase as the signal becomes available or more informative, respectively. Instead, there is a range of natural situations in which more contractually employable information leads to less efficiency and lower welfare overall. Thus, the general view that distortions in agency are mitigated as additional information of the agent's type becomes available ex post (e.g., through monitoring) may often prove to be incorrect.

As a second result, we have seen that the qualitative effects of additional information can unambiguously be tied to the nature of the underlying problem, namely, of whether the agent is in a "buyer" or a "seller" position. If the agent's utility is strictly increasing in the contractually specified action, we found that downward distortions will be strengthened if the signal is not too informative. Conversely, additional information may result in upward (instead of downward) distortions if the agent's utility is strictly decreasing in the contractually specified action. Finally, we showed that in all instances in which the agent is in the seller position, he may also command a higher informational rent in the presence of an informative signal relative to the case in which no additional information is available.

We believe that these findings are potentially of great importance, depending on the application at hand. Although we have deliberately formulated the model

[24] See the Appendix for a simple example.

in general terms and more work specifically addressing the respective real-world situation is needed, there are some tentative conclusions that can be drawn from our analysis. Take first the case where the agent is in a buyer position. In the monopolistic seller application we used in the text, for instance, our results imply that the equilibrium volume of trade can drop as manufacturers use more information in their contractual relations with their retailers. Similarly, in the context of environmental regulation, the government may adopt less tight emission standards as more precise monitoring techniques become available. Even more importantly, in a credit market with adverse selection, the equilibrium volume of loans may actually fall as banks make use of additional information on their customer's creditworthiness. This is true even though banks profit from the possibility to monitor their customer's behavior or credit history. But as our analysis indicates, the welfare implications of this usage of information may well be negative and regulations may therefore be called for.

Next, consider the case where the agent is in a seller position. This situation encompasses many applications in trade and procurement, regulation, or employment relationships found in the literature. In the procurement example used in the text, for instance, the results imply that for high-cost high-quality producers the volume of trade may be inefficiently large as warranties or breach penalties become available. In an employment context, less productive workers may be required to put in excessive work hours if their employer employs an informative but sufficiently noisy monitoring technology. Overall welfare will then be lower as compared to a situation in which warranties or monitoring are not an option, respectively. However, depending on the informativeness of the signal (e.g., the implied variance in durability of the product, the accuracy of the audit) our results also show that the agent may benefit from the contractual terms being contingent on ex post information, e.g., suppliers from warranties and managers from audits, respectively. In these instances, we can conclude that the usage of additional information is unambiguously welfare enhancing.

Although we have used a very simple framework to highlight the economic forces at work, there are strong reasons to believe that our conclusions are fairly robust to various modifications and extensions of the model. In particular, they should qualitatively carry over to a model in which the agent's private information is drawn from a continuous (instead of binary) distribution. Unfortunately, generalizing our model to the continuous case has been beyond the scope of this article, not least because standard solution methods are unlikely to be applicable. In particular, it will be difficult to validate the first-order approach in a framework where the monotonicity of the contracted action is neither necessary nor sufficient for its implementability.[25] Once these technical difficulties are overcome, however, we see no reason why the rationale underlying our results, which is strong and intuitive, should not carry over: The less an agent in a buyer position has to purchase,

[25] Demougin and Garvie (1991) assume that the agent's utility function is linear in his output. For this special case and under an additional assumption on the elasticity of the (binary) signal with respect to agent type, they show that the local first-order conditions for truth telling imply global incentive compatibility. However, the validity of the first-order approach does not extend to nonlinear utility functions, which would render an analysis of continuous type spaces extremely difficult.

the more money is left in his pocket to serve as a penalty. Trade volume may thus fall (and so will efficiency) as additional information makes penalties an option. Likewise, the more an agent in a seller position has to produce, the higher his compensation and the more can be withheld from him as a penalty. Trade volume will thus rise (possibly reducing efficiency) as additional information makes penalties an option.

This line of argument also provides some insights as to whether our results are preserved in a variant of our model in which the signal is observed after the contract has been signed but before the transaction has taken place.[26] In this scenario, the transaction itself—in addition to the transfers—can be conditioned on the outcome of the signal. The link between penalties and the (expected) level of transaction is still present, however, which leads us to conjecture that our qualitative results are unaffected. To see this, consider an agent in a buyer position. It is still true that the less he buys from the principal on average, the more money is left in his pocket to serve as a penalty. Hence, the principal still can—and sometimes should—reduce the average volume of trade to increase the endogenous punishment. How should she use the additional degree of freedom in making trade volumes contingent on the signal outcome? Intuitively, even if average trade volume falls, she should trade more if the signal indicates compliance: Being more confident that the agent has announced the truth, the principal should increase efficiency. If the signal indicates noncompliance, however, it should be optimal to trade even less by the same argument, i.e., efficiency should be reduced even further. Similarly, if the agent is in a seller position, a higher average volume of trade will continue to provide a basis for larger penalties as the principal can withhold the promised payments. If the signal was favorable, it is likely that the principal will again increase the quantity traded as long as this is efficiency enhancing. For unfavorable signals, an excessive production level may once again be optimal: Not only does it serve to increase the expected penalty, but it also directly punishes the agents who dislike production.

What is important for our results, however, is our interpretation of the agent's limited liability as the principal's inability to extract money from the agent, i.e., there was a maximum upper bound (possibly negative) on the amount of monetary transfers from the agent to the principal. These transfer payments are the sum of the regular transfer payment to be made in the transaction and a possible punishment (a breach penalty) if the signal indicates the agent's noncompliance. A crucial consequence is that the maximum punishment to be inflicted on an agent is endogenous, i.e., it is positively (agent-buyer) or negatively (agent-seller) related to the regular transaction payment and hence to the contractual terms of trade. Although our interpretation of limited liability is not novel, the literature often subscribes to an alternative understanding, according to which the agent's

[26] Although this possibility does not necessarily lend itself naturally to some settings (e.g., warranties can only take effect after a purchase and an audit can detect fraud or noncompliance only after the required task has been carried out), there are other instances in which information may be available prior to the transaction. We wish to thank an anonymous referee for making us aware of this variant.

maximum punishment is fixed at some exogenous level and is thus functionally unrelated to other contractual provisions between the parties. As is easily seen, all of our main results will no longer hold if instead the penalty is exogenous. Our analysis as well as previous work (e.g., Kofman and Lawarrée, 1993; Khalil; 1997) thus indicates that the implications are qualitatively very different depending on which interpretation is adopted. Obviously, whether one or the other is more realistic depends on the specifics of the situation, and additional research in this area would therefore be desirable. In particular, we are not aware of any contribution that links the theory to actual legal practice, i.e., examines what options are legally available to the parties and to what extent courts enforce contractually prescribed penalties and damage clauses.

Finally, several extensions of our model could be considered. In particular, we have treated the ex post signal itself as well as its informativeness as exogenously given. A natural extension of our model would allow for the information to be observed only if the principal conducts costly audits or for an endogenous choice of the informativeness of the signal. As the principal's payoff is always higher if the signal is available and monotonically increasing in its precision, neither extension is likely to change our qualitative insights.[27] Another and perhaps more promising extension concerns the possibility that the agent himself can affect the signal that is received by the principal. In the manufacturer–retailer example, for instance, the agent's private information may relate to demand conditions and he may be able to influence the price of final output that is produced using the principal's input. Then, the equilibrium signal itself will depend on the contracting terms and thus be chosen endogenously. More generally, suppose the agent can manipulate ex post information at some personal cost. Our findings then suggest that, surprisingly, total surplus could actually be enhanced if the agent's cost of manipulating ex post information decreases.[28] Moreover, the agent may be better off if he can release some public information ex post, which may be an interesting topic for future research.

APPENDIX

The optimal contract $\{(t_i^S(s_j), x_i^S)\}_{i,j=l,h}$ solves the program (P), the solution of which is characterized in the lemma below. Define

$$\Phi(x,\pi) \equiv u(x,\theta_h) - \frac{1-\pi}{\pi}u(x,\theta_l) - \frac{2\pi-1}{\pi}(\bar{u}+W)$$

[27] This argument notwithstanding, taking the choice of monitoring as exogenous may lead to wrong conclusions regarding the effects of variations in the informativeness of the signal on the variables of the model (see Demougin and Fluet, 2001). Also observe that since the agent is punished with positive probability in equilibrium, the principal might find it optimal to conduct costly audit even if she cannot commit to do so ex ante.

[28] See Maggi and Rodríguez-Clare (1995) for a related result in a model based on countervailing incentives.

and note that

(A.1) $$\hat{x}_l(\pi) = \arg\max_{x\in[\underline{x},\bar{x}]} S(x,\theta_l) - \frac{q}{1-q}\Phi(x,\pi)$$

LEMMA 1. *The optimal contract* $\{x_i^S, t_i^S\}$ *always prescribes* $x_h^S = x_h^{\mathrm{FB}}$. *For values of* $\pi \geq \pi^{\mathrm{FB}}$, *we have* $x_l^S = x_l^{\mathrm{FB}}$ *and* $\Phi(x_l^S,\pi) \leq 0$. *For* $\pi < \pi^{\mathrm{FB}}$, x_l^S *is characterized by*

(a) $\Phi\,(x_l^S,\pi) = 0$ *if* $\Phi(\hat{x}_l(\pi),\pi) \leq 0$,
(b) $x_l^S = \hat{x}_l(\pi)$ *otherwise.*

The transfers under this contract are $t_l^S(s_h) = -W$, $t_l^S(s_l) = [\bar{u} - u(x_l^S,\theta_l) + (1-\pi)W]/\pi$ *and* $t_h^S(s_h) = t_h^S(s_l) = \bar{u} - u(x_h^{\mathrm{FB}},\theta_h) + \max\{\Phi(x_l^S,\pi), 0\}$.

PROOF. Note first that by invoking the Maximum Punishment Principle (Baron and Besanko, 1984), we can set $t_l(s_h) = -W$ and let $t_l(s_l) \equiv t_l$ for brevity of exposition. Second, provided the (IC_l) constraint is slack, we can without loss of generality assume that $t_h(s_h) = t_h(s_l) \equiv t_h$. In what follows, we will ignore the (IC_l) constraint and later verify that it is indeed not binding in the optimum. Furthermore, since $t_h^S \geq \bar{u} - u(x_h^{\mathrm{FB}},\theta_h) \geq -W$ by (3), the wealth constraint for the θ_h-type agent will not be binding and can be ignored. Similarly, for values $\pi \geq \pi^{\mathrm{FB}}$ we have $x_l^S = x_l^{\mathrm{FB}}$, implying $t_l^S \geq -W$ by (3). An argument that the wealth constraint $t_l \geq -W$ is not binding for $\pi < \pi^{\mathrm{FB}}$ is deferred to the proofs of Propositions 1 and 2 below. Rewriting the principal's payoff and the remaining constraints, the Lagrangian of the principal's problem is

$$\begin{aligned}\mathcal{L} &= q\,[v(x_h,\theta_h) - t_h] + (1-q)\,[v(x_l,\theta_l) - \pi t_l + (1-\pi)W] \\ &\quad + \lambda_l\left\{\pi t_l - (1-\pi)W + u(x_l,\theta_l) - \bar{u}\right\} + \lambda_h\left\{t_h + u(x_h,\theta_h) - \bar{u}\right\} \\ &\quad + \mu\left\{t_h + u(x_h,\theta_h) - (1-\pi)t_l + \pi W - u(x_l,\theta_h)\right\}\end{aligned}$$

The first-order conditions are

(A.2) $$\frac{\partial\mathcal{L}}{\partial x_h} = qv'(x_h,\theta_h) + (\lambda_h + \mu)u'(x_h,\theta_h) = 0$$

(A.3) $$\frac{\partial\mathcal{L}}{\partial t_h} = -q + \lambda_h + \mu = 0$$

(A.4) $$\frac{\partial\mathcal{L}}{\partial x_l} = (1-q)v'(x_l,\theta_l) + \lambda_l u'(x_l,\theta_l) - \mu u'(x_l,\theta_h) = 0$$

(A.5) $$\frac{\partial\mathcal{L}}{\partial t_l} = -(1-q)\pi + \lambda_l\pi - \mu(1-\pi) = 0$$

Inserting (A.3) into (A.2), using $S(x,\theta) = v(x,\theta) + u(x,\theta)$, yields

$$S'(x_h,\theta_h) = 0 \;\Rightarrow\; x_h^S = x_h^{\mathrm{FB}}.$$

Next, (A.5) implies $\lambda_l = (1-q) + \mu\frac{1-\pi}{\pi} > 0$. Thus, ($IR_l$) is always binding. We can substitute λ_l in (A.4) to obtain

$$S'(x_l, \theta_l) = \frac{\mu}{1-q}\left[u'(x_l, \theta_h) - \frac{1-\pi}{\pi}u'(x_l, \theta_l)\right] \tag{A.6}$$

Consider first $\mu = 0$. Then, $x_l = x_l^{FB}$ by (A.6) and $\lambda_h = q > 0$ from (A.3), so (IR_h) is satisfied with equality. Since (IR_l) is binding, in order for (IC_h) to hold in this case, we must have

$$u(x_l^{FB}, \theta_h) - \frac{1-\pi}{\pi}\left[u(x_l^{FB}, \theta_l) - \bar{u}\right] - \frac{2\pi - 1}{\pi}W \le \bar{u}$$

which is equivalent to $\Phi(x_l^{FB}, \pi) \le 0$ or $\pi \ge \pi^{FB}$ as defined in the text. Conversely, for $\pi < \pi^{FB}$, $\mu = 0$ yields a contradiction, so (IC_h) is binding. There are two cases to distinguish:

(a) $\lambda_h > 0$ implies that both (IR_h) and (IC_h) are binding at the optimum. x_l^S is then implicitly characterized by

$$\Phi(x_l^S, \pi) = u(x_l^S, \theta_h) - \frac{1-\pi}{\pi}u(x_l^S, \theta_l) - \frac{2\pi - 1}{\pi}(\bar{u} + W) = 0$$

(b) $\lambda_h = 0$ yields $\mu = q$ from (A.3) and x_l^S can be recovered from Equation (A.6),

$$S'(x_l^S, \theta_l) = \frac{q}{1-q}\left[u'(x_l^S, \theta_h) - \frac{1-\pi}{\pi}u'(x_l^S, \theta_l)\right] \tag{A.7}$$

implying $x_l^S = \hat{x}_l(\pi)$. Note that $\lambda_h = 0$ requires $\Phi(\hat{x}_l(\pi), \pi) \ge 0$.

To complete the proof, it remains to show that (IC_l) is not binding. Using (IR_l) and (IC_h), this constraint can be written as

$$u(x_h^{FB}, \theta_l) - u(x_h^{FB}, \theta_h) + \max\left\{\Phi(x_l^S, \pi), 0\right\} \le 0 \tag{A.8}$$

Observe first that if $\Phi(x_l^S, \pi) \le 0$, inequality (A.8) is implied by Assumption 1 (a). Thus, we can confine attention to case (b) where (IR_h) is not binding and $x_l^S = \hat{x}_l(\pi)$. Next, note that for (A.8) to hold it suffices to prove that $\Phi(x_l^S, \pi) \le \Phi(x_l^{FB}, 1/2)$, because $\Phi(x_l^{FB}, 1/2) = u(x_l^{FB}, \theta_h) - u(x_l^{FB}, \theta_l)$, so (A.8) will again be satisfied by Assumptions 1 (b) and (c). Consider the following alternative contract: $x_i = x_i^{FB}$, $t_l(s_l) = t_l(s_h) = \bar{u} - u(x_l^{FB}, \theta_l)$ and $t_h = \bar{u} - u(x_h^{FB}, \theta_h) + \Phi(x_l^{FB}, 1/2)$. Since this contract satisfies all the constraints, the principal's expected utility under the optimal contract must weakly exceed her expected utility under the alternative contract. Hence,

$$S(x_l^S, \theta_l) - \frac{q}{1-q}\Phi(x_l^S, \pi) \geq S(x_l^{\text{FB}}, \theta_l) - \frac{q}{1-q}\Phi\left(x_l^{\text{FB}}, \frac{1}{2}\right)$$

by revealed preferences. The claim follows from $S(x_l^{\text{FB}}, \theta_l) \geq S(x_l^S, \theta_l)$ by definition of x_l^{FB}. ■

A.1. *Proof of Proposition 1.* As Lemma 1 already characterizes x_h^S as well as x_l^S for $\pi \geq \pi^{\text{FB}}$, we focus on how x_l^S varies with π for $\pi < \pi^{\text{FB}}$. Suppose $u'(x, \theta_i) > 0\ \forall x \in [\underline{x}, \bar{x}]$ and recall from Section 3 that at $\pi = 1/2$, $x_l^S = x_l^{\text{SB}} = \hat{x}_l(1/2)$ and $\Phi(x_l^{\text{SB}}, 1/2) > 0$. Since the objective function in (A.1) has decreasing marginal returns, $\hat{x}_l(\pi)$ is a strictly decreasing function of π (see, e.g., theorem 1 in Edlin and Shannon, 1998).[29] Also note that

$$\text{(A.9)} \qquad \frac{d\Phi(\hat{x}_l(\pi), \pi)}{d\pi} = \frac{\partial\Phi(\hat{x}_l(\pi), \pi)}{\partial\pi} + \frac{\partial\Phi(\hat{x}_l(\pi), \pi)}{\partial\hat{x}_l}\frac{\partial\hat{x}_l}{\partial\pi}$$
$$= -\frac{1}{\pi^2}\left[\bar{u} + W - u(\hat{x}_l, \theta_l)\right] + \frac{1-q}{q}S'(\hat{x}_l, \theta_l)\frac{\partial\hat{x}_l}{\partial\pi}$$

where we have used the definition of $\Phi(\cdot)$ and the fact that $\hat{x}_l$ satisfies the first-order condition (A.7) to program (A.1). Due to $\partial\hat{x}_l(\pi)/\partial\pi < 0$, we must have $\hat{x}_l < x_l^{\text{SB}}$ and, hence, $S'(\cdot) > 0$ and $\bar{u} + W - u(\hat{x}_l, \theta_l) > 0$ using (3) and $u'(\cdot) > 0$. Therefore, $d\Phi/d\pi < 0$, i.e., the agent's rent is decreasing in π as one would expect. Since $\Phi(\hat{x}_l(\pi^{\text{FB}}), \pi^{\text{FB}}) < \Phi(x_l^{\text{FB}}, \pi^{\text{FB}}) = 0$, there exists a unique $\hat{\pi} \in (1/2, \pi^{\text{FB}})$ such that $\Phi(\hat{x}_l(\hat{\pi}), \hat{\pi}) = 0$. Now consider increasing π from 1/2 to $\hat{\pi}$, i.e., over the range where $\Phi(x_l^S, \pi) > 0$ so that the (IR_h) constraint is not binding. Then, we are in case (b) of Lemma 1 and $x_l^S = \hat{x}_l(\pi)$. Hence, x_l^S is decreasing in π for $\pi \in [1/2, \hat{\pi})$. At $\hat{\pi}$, the (IR_h) constraint becomes binding. For values $\hat{\pi} \leq \pi \leq \pi^{\text{FB}}$, we are in case (a) of Lemma 1, where x_l^S is implicitly determined by $\Phi(x_l^S, \pi) = 0$. By the implicit function theorem,

$$\text{(A.10)} \qquad \frac{\partial x_l^S}{\partial\pi} = -\frac{\partial\Phi(\cdot)/\partial\pi}{\partial\Phi(\cdot)/\partial x_l^S} = -\frac{-\frac{1}{\pi^2}\left[\bar{u} + W - u(x_l^S, \theta_l)\right]}{\frac{1-q}{\mu}S'(x_l^S, \theta_l)}$$

which is strictly positive as $x_l^S \leq x_l^{\text{FB}}$ using a similar argument as above. Continuity follows from the Theorem of the Maximum. To summarize, x_l^S at first decreases in π below x_l^{SB}, obtains a minimum at $\hat{\pi}$, and then increases again until $x_l^S = x_l^{\text{FB}}$ at $\pi = \pi^{\text{FB}}$. The existence of the critical value $\underline{\pi}$ as stated in Proposition 1 now follows from an intermediate value argument. Finally, note that (3) and $x_l^S \leq x_l^{\text{FB}}$ together with $u' > 0$ ensure that $\bar{u} + W - u(x_l^S, \theta_l) \geq 0$ over the entire range. This implies $t_l^S \geq -W$, so that the contract characterized in Lemma 1 also satisfies the wealth constraint for the θ_l-type agent. ■

[29] A function $f(x, t)$ is said to display increasing (decreasing) marginal returns, if $\partial f/\partial x$ is strictly increasing (decreasing) in t. This property is sometimes also referred to as (strict) supermodularity.

A.2. *Proof of Proposition 2.* Suppose $u'(x, \theta_i) < 0\ \forall x \in [\underline{x}, \bar{x}]$. Again, we confine attention to the case where $\pi < \pi^{\mathrm{FB}}$ and investigate how x_l^S varies with π, starting from $x_l^S = x_l^{\mathrm{SB}} = \hat{x}_l(1/2)$ at $\pi = 1/2$. Due to $u' < 0$, the objective function in (A.1) has increasing marginal returns and $\hat{x}_l(\pi)$ is therefore a strictly increasing function of π. Since $\Phi(\hat{x}_l(1/2), 1/2) > 0$, case (b) of Lemma 1 again applies for π sufficiently close to 1/2, implying $x_l^S = \hat{x}_l(\pi)$. Moreover, note that $\bar{\pi}$ as defined in the text is such that $\hat{x}_l(\pi) \geq x_l^{\mathrm{FB}} \Leftrightarrow \pi \geq \bar{\pi}$. There are two possibilities to consider.

First, if $\pi^{\mathrm{FB}} < \bar{\pi}$, then $\hat{x}_l(\pi) < x_l^{\mathrm{FB}}$ for all $\pi \leq \pi^{\mathrm{FB}}$. Since $\partial\Phi/\partial\hat{x}_l > 0$ for $\hat{x}_l < x_l^{\mathrm{FB}}$, we have $\Phi(\hat{x}_l(\pi^{\mathrm{FB}}), \pi^{\mathrm{FB}}) < \Phi(x_l^{\mathrm{FB}}, \pi^{\mathrm{FB}}) = 0$, so that by continuity there must exist a $\hat{\pi} \in (1/2, \pi^{\mathrm{FB}})$ with $\Phi(\hat{x}_l(\hat{\pi}), \hat{\pi}) = 0$ such that x_l^S is characterized as in Lemma 1 (a) for $\pi \geq \hat{\pi}$. Over this range, $\Phi(x_l^S, \pi) = 0$, so that x_l^S continues to be increasing (see (A.10) and note that $x_l^{\mathrm{SB}} < x_l^S < x_l^{\mathrm{FB}}$). Hence, x_l^S monotonically increases in this case from x_l^{SB} to x_l^{FB} as π varies from $1/2$ to π^{FB}. Second, we may have $\bar{\pi} < \pi^{\mathrm{FB}}$, so that $\hat{x}_l(\pi) > x_l^{\mathrm{FB}}$ for all $\pi \in (\bar{\pi}, \pi^{\mathrm{FB}}]$. From $\partial\Phi/\partial\hat{x}_l < 0$ for $\hat{x}_l > x_l^{\mathrm{FB}}$, it follows again that $\Phi(\hat{x}_l(\pi^{\mathrm{FB}}), \pi^{\mathrm{FB}}) < \Phi(x_l^{\mathrm{FB}}, \pi^{\mathrm{FB}}) = 0$. Furthermore, $\Phi(\hat{x}_l(\bar{\pi}), \bar{\pi}) = \Phi(x_l^{\mathrm{FB}}, \bar{\pi}) > \Phi(x_l^{\mathrm{FB}}, \pi^{\mathrm{FB}}) = 0$, because $\partial\Phi/\partial\pi < 0$. By continuity there thus exists a $\hat{\pi} \in (\bar{\pi}, \pi^{\mathrm{FB}})$ with $\Phi(\hat{x}(\hat{\pi}), \hat{\pi}) = 0$ such that x_l^S is characterized as in Lemma 1 (a) for $\pi \geq \hat{\pi}$. Over this range, x_l^S is decreasing in π as can be seen from (A.10) using $x_l^{\mathrm{FB}} < x_l^S$. To summarize, for $\bar{\pi} < \pi^{\mathrm{FB}}$, x_l^S at first increases in π above x_l^{FB} for $\pi > \bar{\pi}$, obtains a maximum at $\hat{\pi}$, and then decreases again until $x_l^S = x_l^{\mathrm{FB}}$ at $\pi = \pi^{\mathrm{FB}}$. Again, it is straightforward to show that $\bar{u} + W - u(x_l^S, \theta_l) \geq 0$ over the entire range, which implies $t_l^S \geq -W$, so that the contract characterized in Lemma 1 is indeed optimal. ■

A.3. *Proof of the Corollary.* The first part of the corollary follows immediately from the proof of Proposition 1. In order to prove the second part, suppose $u'(x, \theta_i) < 0$. The agent's rent is given by $\max\{\Phi(\hat{x}_l(\pi), \pi), 0\}$, where $\Phi(\hat{x}_l(\pi), \pi)$ varies with π according to (A.9). The first term in (A.9) is negative due to $\hat{x}_l \geq x_l^{\mathrm{SB}}$ and (3). The second term is also negative if $\hat{x}_l(\pi) \geq x_l^{\mathrm{FB}}$, which is equivalent to $\pi \geq \bar{\pi}$. For $\hat{x}_l(\pi) < x_l^{\mathrm{FB}}$, however, the second term is positive. It is straightforward to construct examples in which the second effect overcompensates the first effect for some $\pi < \bar{\pi}$. For instance, let $u(x, \theta) = -(1/2)(x - \theta)^2$, $v(x, \theta) = x$, $q = 0.5$, $\theta_l = 0.5$, $\theta_h = 1$, $\underline{x} = 1$, $\bar{x} = 3$, and $W = \bar{u} = 0$. It can easily be verified that $\bar{\pi} = 2/3$ and $\pi^{\mathrm{FB}} = 0.8$, and that the agent's rent is increasing for $\pi \in [0.5, 0.6]$. ■

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