Knowing your Lemon before you Dump It

Online Supplement

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Abstract

This document contains additional material mentioned in the paper. All sections, conditions, and results specific to this document have the suffix "S" to avoid confusion with the corresponding parts in the main text. Section S.1 contains examples of generalized lemons games, as well as an example in which the follower's reaction to both the leader's choice to engage as well as not to engage depends on his beliefs of what motivated the leader's action. Section S.2 introduces anti-lemons games and shows how the condition for expectation conformity changes when Assumption 3 in the main text is replaced by its anti-lemon counterpart, Assumption 3'. Section S.3 discusses the connection to other covert investment games. Section S.4 contains a few results for the outer game in the Akerlof model with flexible information acquisition under entropy cost in which the marginal cost of entropy reduction is endogenized.

S.1 Examples of Generalized Lemons Games

In this section, we show how a number of games of interest fit into the general model of Section 2 in the paper.

(a) ***Jumpstarting frozen markets and related asset-purchasing programs***. The suboptimal volume of trade in Akerlof's model motivates policy interventions (see also the analysis in Section 5 in the paper). Consider a government that, in the context of the Akerlof model in the main text, maximizes total welfare. The government can neither coerce the agents to trade nor prevent the existence of a free private market. However, it can influence the market outcome by purchasing some of the assets. The shadow cost of public funds used for such purchases is $1+\lambda$, with $\lambda > 0$. The

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government, just like private buyers, does not know ω and values the assets at $\omega + \Delta$. Philippon-Skreta (2012) and Tirole (2012) show that, when the sellers' information is exogenous, the optimal policy has a simple form: The government purchases the lowest-quality assets, the market the intermediate-quality ones, and the best-quality assets are kept by the sellers. Furthermore, the optimum can be implemented by the government setting a price r so as to maximize

$$\max_r \left\{ G(r;\rho^\dagger) \left[\Delta - \lambda \left(r - M^-(r;\rho^\dagger) - \Delta \right) \right] \right\}, \tag{S.1}$$

where $\rho^\dagger$ indexes the sellers' information.[1] The first-term in the square bracket is the gain from trade, whereas the second term in the square brackets represents the deadweight loss on the deficit, reflecting the fact that, when the competitive private market breaks even, it is *as if* the government purchases all tendered assets itself.[2] The first-order condition for the optimal choice of r is[3]

$$\frac{g(r;\rho^\dagger)}{G(r;\rho^\dagger)} = \frac{\lambda}{(1+\lambda)\Delta}. \tag{S.2}$$

Under the same differentiability and convexity assumptions as in the Akerlof model in the main text, we then have that the sellers' choice of information satisfies $-\int_r^{+\infty} G_\rho(m;\rho)dm = C'(\rho)$, as in the Akerlof model. The only difference is that r is now chosen by the government instead of being determined by the market.

(b) ***Partnerships***. Player L has a project. She can associate player F to it or do it alone. Bringing player F on board creates synergies (lowers the cost of implementation), but forces L to share the gains, which she does not want to do if the project is a good one. Player L's payoff is $\omega - d_L$ if she does it alone and $r\omega - c_L$ if it is a joint project, where r is the value share left to L by (competitive) player F and c_L is player L's reduced cost of project implementation. Let c_F denote player F's cost, with $c_L + c_F < d_L$. Given her posterior mean m, player L chooses $a = 1$ if and only if $\delta_L(r, m) = d_L - c_L - (1-r)m \geq 0$. Provided that $m > 0$, Assumption 2 (monotonicity) is then

[1] To see this, let m^g denote the critical threshold below which a seller of an asset of quality m sells to the government. The social cost of the government's program is then equal to $\lambda \left\{ r - \mathbb{E}_{G(\cdot;\rho^\dagger)}[m | m \leq m^g] - \Delta \right\} G(m^g;\rho^\dagger)$, which accounts for the fact that the government can resell the assets at price $\mathbb{E}_{G(\cdot;\rho^\dagger)}[m | m \leq m^g] + \Delta$, and the proceeding from the sale can be used to reduce the distortions associated with future needs to collect money from taxpayers. The non-arbitrage condition between the government's program and the private market, along with the fact that buyers are competitive, then implies that $r = \mathbb{E}_{G(\cdot;\rho^\dagger)}[m | m \in [m^g, r]] + \Delta$. Combining the two conditions above and using the law of iterated expectations, we have that

$$M^-(r;\rho^\dagger) = \frac{G(m^g;\rho^\dagger)}{G(r;\rho^\dagger)} \mathbb{E}_{G(\cdot;\rho^\dagger)}[m | m \leq m^g] + \frac{G(r;\rho^\dagger) - G(m^g;\rho^\dagger)}{G(r;\rho^\dagger)} \mathbb{E}_{G(\cdot;\rho^\dagger)}[m | m \in [m^g, r]]$$

which gives the formula in (S.1).

[2] It is important, though, that the government does not buy all these assets and lets the market rebound. Otherwise, the market would nonetheless rebound, and the sellers' anticipation of this rebound would force the planner to buy assets at an even higher price: See the papers mentioned above for details.

[3] The condition uses the fact that $\partial M^-(r;\rho^\dagger)/\partial m^* = g(r;\rho^\dagger)[r - M^-(r;\rho^\dagger)]/G(r;\rho^\dagger)$.

satisfied. Finally, $r = r(\rho^\dagger)$ solves

$$(1-r)M^-\left(\frac{d_L - c_L}{1-r};\, \rho^\dagger\right) = c_F. \tag{S.3}$$

Provided that (S.3) has one and only one solution, then Assumption 3 (lemons) is also satisfied.[4]

(c) ***Disclosure of Hard Information***. In another important variant of Akerlof's model, the seller wants to sell for sure (she has no value for the good, say), and either has no information about ω (with probability $1-\rho$) or knows ω (with probability ρ), as in Dye's (1985) model. So $G(m;\rho) = \rho G(m)$ for $m < \omega_0$ and $G(m;\rho) = \rho G(m) + 1 - \rho$ for $m \geq \omega_0$, where ω_0 is the prior mean of G (note that this is the same structure as in the directed-search technology in the main text). In contrast with Akerlof's soft-information lemons game, the seller's decision is not whether to put the good for sale (a foregone conclusion), but whether to reveal the state of Nature when knowing it. A well-established literature, surveyed by Milgrom (2008), has studied such an incentive to disclose. A natural extension of the disclosure model consists in thinking of ρ (the precision of information) as endogenous.

In order to apply the general results, we must define the actions and the corresponding δ_L function. Let $a = 1$ stand for the decision of non disclosing and $a = 0$ for the decision of disclosing the state of Nature. The rationale for this choice is that player F's beliefs about player L's information matter only if there is no disclosure. As in the Akerlof model in the main text and in Example (a) above, let $\omega + \Delta$ denote the buyer's utility. Then let r denote the price offered by the buyer in the absence of disclosure. The seller thus obtains $m + \Delta$ if she discloses, and r if she does not disclose, so that $\delta_L(r, m) = r - (m + \Delta)$, implying that Assumption 2 (monotonicity) in the main text is satisfied.

To compute $r(\rho^\dagger)$, note that, when information is exogenously fixed at $\rho^\dagger$, the seller discloses if and only if she is informed and $m > m^*(r) = r - \Delta$. Hence $r(\rho^\dagger)$ solves

$$r = \frac{(1-\rho^\dagger)\omega_0 + \rho^\dagger \displaystyle\int_{-\infty}^{r-\Delta} m dG(m)}{1 - \rho^\dagger + \rho^\dagger G(r-\Delta)} + \Delta. \tag{S.4}$$

In this setting, the expected value of m conditional on player L engaging (i.e., not disclosing) does not coincide with $M^-\left(m^*(r(\rho^\dagger));\, \rho^\dagger\right)$. This is because player L, when not receiving any information, has no choice but to engage, irrespective of whether her posterior expected value of ω (which is equal to ω_0) is below or above m^*.[5] The analog of Assumption 3 (lemons) in the main text in this setting

[4] Note that for (S.3) to admit one and only one solution it must be that $M^-\left(d_L - c_L;\, \rho^\dagger\right) \geq c_F$. When this condition holds, (S.3) admits at least one solution. Such a solution is unique if, and only if, in addition to the condition above, $c_F - \frac{\partial}{\partial m^*}M^-\left(\frac{d_L - c_L}{1-r};\, \rho^\dagger\right)(d_L - c_L) > 0$ for any r that solves (S.3). The last property always holds when $G(m;\rho^\dagger)/g(m;\rho^\dagger)$ is increasing in m and $c_F > d_L - c_L$ for, in this case, $\frac{\partial}{\partial m^*}M^-\left(\frac{d_L - c_L}{1-r};\, \rho^\dagger\right) \in (0,1)$.

[5] Furthermore, it is easy to see that any solution to (S.4) is such that $\omega_0 > r - \Delta = m^*(r)$.

is that the sign of $dr(\rho^\dagger)/d\rho^\dagger$ coincides with the sign of $\partial \hat{M}\left(r(\rho^\dagger);\, \rho^\dagger\right)/\partial\rho^\dagger$ where, for any $(r, \rho^\dagger)$

$$\hat{M}\left(r;\, \rho^\dagger\right) \equiv \frac{(1-\rho^\dagger)\omega_0 + \rho^\dagger \int_{-\infty}^{r-\Delta} m dG(m)}{1-\rho^\dagger+\rho^\dagger G(r-\Delta)}$$

denotes the expected value of m conditional on L engaging optimally against a reaction of r by F, under information $\rho^\dagger$. It is easy to see that this is the case whenever the solution to (S.4) is unique, which is always the case when $r - \hat{M}\left(r;\, \rho^\dagger\right)$ is increasing in r.

(d) ***(Interdependent herding) entry games***. Firm L decides whether to enter a market. Firm F then decides whether to follow suit. Firm F uses the information revealed by firm L's decision, but, in contrast with most herding models, payoffs are interdependent and so externalities are not purely informational. Suppose for instance that L and F are rivals, with per-customer profit π^m under monopoly and $\pi^d < \pi^m$ under duopoly.[6] The state of Nature ω here represents information correlated with the two firms' entry costs. Specifically, assume that firm L's entry cost is ω whereas firm F's entry cost is $\omega + \varepsilon$, where ε is drawn from $\mathbb{R}$, according to the distribution $H(\varepsilon)$ with density $h(\varepsilon)$, independently from ω. Importantly, the realization of ε is unknown to firm L when it decides whether to enter. Let r denote the probability of non-entry by firm F and let m denote firm L's posterior expected value of ω. We then have that

$$\delta_L(r, m) \equiv \left[r\pi^m + (1-r)\pi^d\right] - m,$$

implying that $m^*(r) = r\left(\pi^m - \pi^d\right) + \pi^d$. Assumption 2 (monotonicity) is thus satisfied. In this application, $r(\rho^\dagger)$ is then the solution to $r = 1 - H(\pi^d - M^-\left(m^*(r);\, \rho^\dagger\right))$. Assumption 3 (lemons) is satisfied whenever the solution to this equation is unique, which is the case if the density h of H satisfies $h(\pi^d - M^-\left(m^*(r);\, \rho^\dagger\right)) < 1$, the distribution $G(m; \rho^\dagger)$ of m is such that $G(m;\rho^\dagger)/g(m;\rho^\dagger)$ is increasing in m, which implies that $\partial M^-\left(m^*(r);\, \rho^\dagger\right)/\partial m^* < 1$, and $\pi^m - \pi^d \in (0, 1)$.

(e) ***Marriage***. Consider the following variant of Spier (1992)'s model, augmented with endogenous information. Players L and F decide whether to get married. Getting married has value v_L and v_F for L and F, respectively, provided that all goes well, which has probability ω distributed on $[0, 1]$. With probability $1 - \omega$, instead, things go wrong in which case the players divorce, obtaining utility $v_i - \mathscr{L}_i$, $i = L, F$. The divorce can, however, be made less painful (raising the utility to $v_i - \ell_i$, with $0 < \ell_i < \mathscr{L}_i$, $i = L, F$) through a covenant spelling out the outcome in case of divorce. Adding the covenant costs a fixed amount $c_i < \mathscr{L}_i - \ell_i$ to player $i = L, F$, implying that it is efficient to add the covenant if the parties want to marry but expect to divorce with a sufficiently high probability. The value of v_L is large enough that player L wants to marry regardless of whether the covenant is introduced ($v_L \geq \mathscr{L}_L$). In contrast, player F's value v_F is distributed on $[(1-\omega_0)\mathscr{L}_F, +\infty)$ according to the c.d.f. H and is F's private information. Player L may acquire information about

[6] One can also perform the analysis for complementors, with $\pi^d > \pi^m$.

ω and then chooses between a contract with ($a = 1$) and without ($a = 0$) covenant.[7] Player F then decides whether to accept to marry. Because $v_F - (1-\omega_0)\mathscr{L}_F \geq 0$, in the absence of any information and any covenant, player F always accepts to marry, no matter the realization of v_F. Let r denote the probability that player F accepts to marry when the proposed contract includes the covenant (i.e., when player L engages). This game also satisfies Assumptions 2 (monotonicity) and 3 (lemons). To see this, first note that[8]

$$\delta_L(r,m) = r[v_L - (1-m)\ell_L - c_L] + (1-r)\cdot 0 - [v_L - (1-m)\mathscr{L}_L].$$

Hence, $\delta_L(r,m)$ satisfies Assumption 2. Next, note that, in this example, $m^*(r)$ is given by

$$m^*(r) = \max\left\{\frac{r(v_L - \ell_L - c_L) - (v_L - \mathscr{L}_L)}{\mathscr{L}_L - r\ell_L}; 0\right\}.$$

Hence $r(\rho^\dagger)$ is given by the solution to $r = 1 - H(\ell_F + c_F - M^-(m^*(r);\rho^\dagger)\ell_F)$. Provided that the above equation admits a unique solution (which is the case when $r + H(\ell_F + c_F - M^-(m^*(r);\rho^\dagger)\ell_F)$ is increasing in r) Assumption 3 holds in this example too.

(f) ***Power of incentive scheme (relative adverse selection sensitivity)***. In the main text, as well in all the examples above, F's reaction to $a = 0$ does not depend on F's beliefs about ρ and m. As mentioned in the paper, we expect the results to extend to certain settings in which F's reaction to both of L's actions depends on his beliefs of what motivated L to engage (alternatively to not engage), but with a lower sensitivity when L chooses $a = 0$ than when she chooses $a = 1$. The following example illustrates. Player L is an employee who can choose between a high- and a low-powered incentive scheme (for brevity, HPIS and LPIS). Action $a = 0$ corresponds to the decision to choose HPIS, whereas $a = 1$ corresponds to the decision to choose LPIS. Let y_a denote the employee's "skin in the game," e.g., the amount of shares of the firm held, with $0 \leq y_1 < y_0 \leq 1$. Player F is a (competitive) employer whose payoff is $\kappa + (1-y_a)(e_a + m) - r_a$, where κ is a constant, e_a is the effort optimally exerted by the employee (at increasing and convex private cost $\psi(e)$) after choosing action $a \in \{0,1\}$, and r_a is a fixed wage paid by F to L on top of the money paid through the incentive payment y_a. Hence, in this application, there are two reactions by player F, r_1 and r_0, and each may depend on $\rho^\dagger$. Let $U_L(a, r_a, m)$ and $U_F(a, r_a, m)$ denote the two players' payoffs when player L takes action a, player F reacts with action r_a, and L's posterior mean is m. Then $U_L(a, r_a, m) \equiv \max_e\{r_a + y_a(e+m) - \psi(e)\}$ and $U_F(a, r_a, m) \equiv \kappa + (1-y_a)(e_a + m) - r_a$. Let $r \equiv r_1 - r_0$ and $K_0 \equiv y_1 e_1 - \psi(e_1) - (y_0 e_0 - \psi(e_0))$. Then,

$$\delta_L(r,m) \equiv U_L(1, r_1, m) - U_L(0, r_0, m) = r - (y_0 - y_1)m + K_0.$$

For any r, the engagement threshold is then given by $m^*(r) = (r + K_0)/(y_0 - y_1)$. Let $z \equiv$

[7]As anticipated above, in this application, both actions are adverse-selection sensitive, but $a = 0$ is less so than $a = 1$.

[8]Observe that the absence of a covenant is "good news" about m.

$(1-y_0)/(1-y_1) < 1$ and $K_1 \equiv (1-y_1)e_1-(1-y_0)e_0$ and, for any m^* and $\rho^\dagger$, denote by $M^+(m^*;\, \rho^\dagger) \equiv \mathbb{E}_{G(\cdot;\, \rho^\dagger)}[m|m > m^*]$ the expected value of m under the distribution $G(\cdot;\, \rho^\dagger)$, conditional on m exceeding m^*. Because F is competitive, for any $\rho^\dagger$, $r(\rho^\dagger)$ is then given by the solution to

$$r = K_1 + (1-y_1)\left[M^-(m^*(r);\rho^\dagger) - zM^+(m^*(r);\rho^\dagger)\right].$$

In the model in the main text, $z = 0$. We expect the results to extend to this type of settings provided that (1) δ_L depends only on r and m and satisfies Assumption 1 in the paper (as in this example), (2) z is small so that action $a = 0$ is relatively less "adverse-selection-sensitive" than $a = 1$, and (c) Assumption 3 in the paper holds with respect to $M^- - zM^+$ instead of M^- (which is the case, for example, when m is drawn from a Uniform or a Pareto distribution).

S.2 Anti-Lemons

The analysis in the paper can be adapted to certain environments that do not satisfy Assumption 3. To see this, suppose that the choice of a more informative experiment by L increases the friendliness of F's reaction, instead of reducing it, when it reduces the truncated mean. Assumption 3 in the paper is then reversed and replaced by the following assumption:

Assumption 3′ (anti-lemons). The friendliness of player F;s reaction increases with player L's investment in information if and only if more information reduces the truncated mean:

$$\frac{dr(\rho^\dagger)}{d\rho^\dagger} \overset{\text{sgn}}{=} -\frac{\partial}{\partial\rho^\dagger}\,\mathrm{M}^-\left(\mathrm{m}^*(\mathrm{r}(\rho^\dagger));\, \rho^\dagger\right).$$

The following examples illustrate.

(g) ***Spencian signaling***. An agent (player L) has an uncertain disutility of effort ω for studying which is negatively correlated with the agent's productivity $\theta = a - b\omega$ from working on the relevant job after leaving school. The labor market is populated by competitive employers (player F) offering the agent a wage r equal to the agent's expected productivity, as in Spence (1973). Normalizing L's payoff from not engaging to zero, we have that, in this model, $\delta_L(r,m) = r - m - p$, where p is the cost of enrolling in the school program under consideration (say, an MBA). Hence, the agent enrolls if and only if the perceived cost of studying is low, that is, $m < m^*(r) = r - p$, with r satisfying $r = a - bM^-(m^*(r);\rho^\dagger)$.

(h) ***Start-up followed by liquidation***. An entrepreneur (player L) must decide whether to start a new business. Starting the business costs the entrepreneur $c_L > 0$ and generates cash flows equal to $1-\omega$. Before being able to collect the project's cash flows, the entrepreneur may need to liquidate the project (for example, because of a preference shock that makes consumption at the time the project pays off no longer valuable to L, as in Diamond and Dybvig (1983)). Early liquidation occurs with probability p and results in the entrepreneur collecting a price r for the assets from a pool of risk-neutral competitive investors (player F). The entrepreneur's value from starting the project (i.e., the engagement decision in this application) is equal to $\delta_L = (1-p)(1-m) + pr - c_L$. The entrepreneur thus starts the project if and only if $m < m^*(r) = (1 - p + pr - c_L)/(1-p)$. Assuming, for simplicity, that the value of the project in the investors' hands is also equal to $1-m$, we then have that $r = 1 - M^-(m^*(r); \rho)$. Hence Assumptions 2 (monotonicity) and 3' (anti-lemon) are satisfied.

(i) ***Warfare***. Country L is a potential invader and must decide whether to engage in a fight ($a = 1$) or abstain from doing so ($a = 0$). The state of Nature ω represents the probability that country F wins in case of a fight. Let r denote the probability that country F surrenders without fighting back. The payoff that L obtains in case of victory is 1, whereas the cost of a defeat is c_L, implying that $\delta_L(r, m) = r + (1-r)(1 - m - mc_L)$. Hence Assumption 2 (monotonicity) holds. Furthermore, in this game, L engages if and only if $m \leq m^*(r)$ where

$$m^*(r) = \frac{1}{(1-r)(1+c_L)}.$$

Similarly, letting country F's payoff from victory be equal to 1 and its loss in case of defeat be equal to c_F, we have that country F concedes if and only if

$$M^-(m^*(r(\rho^\dagger)); \rho^\dagger) - \Big(1 - M^-(m^*(r(\rho^\dagger)); \rho^\dagger)\Big)\, c_F \leq 0.$$

Assuming that c_F is drawn from some cumulative distribution H, we then have that $r(\rho^\dagger)$ is given by the solution to

$$r(\rho^\dagger) = 1 - H\left(\frac{M^-(m^*(r(\rho^\dagger)); \rho^\dagger)}{1 - M^-(m^*(r(\rho^\dagger)); \rho^\dagger)}\right). \tag{S.5}$$

Hence, this is an anti-lemon problem, in that the decision by player L to engage carries information that the state is one in which, if player F were to fight back, he would likely lose, thus making F play in a friendlier way towards player L. Whenever equation (S.5) admits a unique solution, Assumption 3' (anti-lemon) then holds: a larger investment in information by player L, when it leads to a reduction in $M^-(m^*(r(\rho^\dagger)); \rho^\dagger)$, induces player F to respond with an action that is friendlier to L (i.e., he surrounds more often).

(j) ***Leadership***. Like in Hermalin (1998)'s theory of leadership, consider a setting in which a leader has information about the profitability of a project and benefits from binging on board a partner. Contrary to Hermalin (1998), however, assume that the leader's information is endogenous. Specifically, suppose that player L's gain from starting the project is $\delta_L(r, m) = 1 - m + r - c_L$, where $1-m$ is the probability that the project succeeds, r is the probability that player F joins the venture, and c_L is L's cost of initiating the project. Hence, Assumption 1 holds. Player F, after observing L's decision to initiate the project, decides whether to join. If he does, his payoff is equal to $1-m+1-c_F$, whereas, if he does not, it is equal to zero. Again, this is an anti-lemon problem, in that the decision by L to engage (here to start a project) is good news for player F, instead of bad news. Assuming that c_F is drawn from some cumulative distribution function H, we then have that the probability that F joins is given by the solution to

$$r(\rho^\dagger) = H\left(2 - M^-\left(1 + r(\rho^\dagger) - c_L; \rho^\dagger\right)\right). \tag{S.6}$$

Hence, Assumption 3' (anti-lemon) holds whenever equation (S.6) admits a unique solution.

S.2.1 Expectation Conformity

Under Assumption $3'$, EC at $(\rho, \rho^\dagger)$ requires that $\mathrm{A}(\rho^\dagger)\mathrm{B}(\rho; \rho^\dagger) > 0$ (the opposite of the condition in Proposition 1 in the paper). Because $\mathrm{A}(\rho^\dagger) < 0 <\mathrm{B}(\rho; \rho^\dagger)$ under the key condition for EC in Proposition 1, namely when

$$\max\left\{G_\rho(m^*(r(\rho^\dagger)); \rho^\dagger), G_\rho(m^*(r(\rho^\dagger)); \rho)\right\} \leq 0,$$

EC never arises when, under the above condition, Assumption 3 in the paper is replaced with Assumption 3'. This is because, when $G_\rho(m^*(r(\rho^\dagger)), \rho^\dagger) \leq 0$, an increase in the informativeness of L's signal triggers a friendlier reaction by player F. In turn, because the marginal value of information decreases with the friendliness of player F's reaction when $G_\rho(m^*(r(\rho^\dagger)), \rho) \leq 0$, an increase in the informativeness of L's signal anticipated by player F (starting from $\rho^\dagger$) reduces the value for L to acquire more information at ρ. Hence EC never arises under the key condition for EC in Proposition 1 in the paper.

The following result summarizes the relationship between expectations and incentives for information acquisition in the anti-lemons case:

Proposition S.1 (***expectation conformity – anti-lemons***). *Suppose that Assumptions 1 and 2 in the paper hold and that Assumption 3 is replaced by Assumption 3'. Further suppose that information reduces the truncated mean* $M^-\big(m^*(r(\rho^\dagger)); \rho^\dagger\big)$*, i.e.,* $\mathrm{A}(\rho^\dagger) < 0$ *(recall that the last property holds when information structures are Uniform, Pareto, or Exponential, or, more generally, when* $G_\rho\Big(m^*\big(r(\rho^\dagger)\big); \rho^\dagger\Big) < 0$*). Then EC holds at* $(\rho, \rho^\dagger)$ *only if*

$$G_\rho\Big(m^*\big(r(\rho^\dagger)\big); \rho\Big) > 0,$$

that is, only if, in L's eyes, a higher ρ increases the probability that L engages. Furthermore, $G_\rho\Big(m^*\big(r(\rho^\dagger)\big); \rho\Big) > 0$ is both necessary and sufficient for EC at $(\rho, \rho^\dagger)$ if $\partial^2\delta_L(m, r)/\partial m\partial r = 0$ for all m and r.

Proof: The proof follows from the arguments above.

Hence, in the case of rotations, EC holds at $\left(\rho, \rho^{\dagger}\right)$ when $m_{\rho^{\dagger}} < m^{*}\left(r(\rho^{\dagger})\right) < m_{\rho}$, that is, when the engagement threshold is between the rotation points $m_{\rho^{\dagger}}$ and m_{ρ} that are relevant for F and L, respectively. This condition is quite stringent. For example, it is never satisfied under non-directed search, for, in that case, $m_{\rho^{\dagger}}{=}m_{\rho} = \omega_0$.

Naturally, many of the results in the paper are reversed when Assumption 3 (lemons) is replaced with Assumption 3' (anti-lemons). For example, disclosure can be effective, and player L may want to appear an "inoffensive fat cat" (in the sense of Fudenberg and Tirole (1984)) in the anti-lemons case. Similarly, it is optimal to subsidize (alternatively, tax) trade when $\frac{d}{ds}M^{-}(m^{*}(r^{*}(0), s); \rho^{*}(s))\big|_{s=0} < K$ (alternatively, when $\frac{d}{ds}M^{-}(m^{*}(r^{*}(0), s); \rho^{*}(s))\big|_{s=0} > K$), where, contrary to the lemons' case, K is a negative scalar.

S.3 Relation to Other Covert Investment Games

The paper's emphasis is on information acquisition, a choice motivated both by the applications and by the fact that many investments are ultimately investments in information processing. But the results may also be useful for other covert investments: capacity acquisition, learning by doing, arms buildup, and so on.

Suppose that there are two players, playing a "second-stage" normal-form game with actions a_L, $a_F \in \mathbb{R}$. One of the players, here player L, makes a "first-stage" investment $\rho \in \mathbb{R}$ at an increasing investment cost $C(\rho)$.[9] Payoffs are $\phi_L(a_L, a_F) - \psi(a_L, \rho) - C(\rho)$ for player L and $\phi_F(a_L, a_F)$ for player F, where all functions are C^2 and satisfy $\partial^2\psi/\partial a_L \partial\rho < 0$ and

$$\frac{\partial^2 \phi_i}{\partial a_i \partial a_j} \begin{cases} > 0 & (SC) \\ \text{or} & \\ < 0 & (SS) \end{cases}$$

for $i, j = L, F$, $j \neq i$.

That is, the investment ρ lowers player L's marginal cost of action a_L, and the strategic interaction between the two players involves either strategic complementarity (SC) or strategic substitutability (SS). For example, a_i may stand for firm i's output, ρ an investment that lowers the marginal cost of production, and the two firms' output choices may be either strategic complements or substitutes.

Assume, for simplicity, that, if player L's investment was common knowledge, the normal-form game in (a_1, a_2) would have a unique and stable equilibrium. In such a game, player F's equilibrium action $a_F(\rho^{\dagger})$ as a function of player L's anticipated investment $\rho^{\dagger}$, is increasing in $\rho^{\dagger}$ under SC and decreasing in $\rho^{\dagger}$ under SS.

Consistently with the analysis in the main text, suppose that player L's actual investment ρ is not observed by player F (so de facto the game is a simultaneous-move game in actions (ρ, a_L), for player L, and a_F, for player F). One can then define player L's optimal action when she deviates

[9] The analysis can be extended to the case where both players make period-1 investments. The insights are not fundamentally different from those discussed here.

from her equilibrium investment. The above assumptions imply that player L's optimal action $a_L(\rho, \rho^\dagger)$ when player F expects $\rho^\dagger$ and player L's actual investment is ρ is non-decreasing in $\rho^\dagger$ under either SC or SS.

This environment is similar to that considered in the industrial organization literature on the taxonomy of business strategies[10], except for one important twist. The investment choice ρ is not observed by player F and so has no commitment effect; rather, what matters for the outcome of the normal-form game is the anticipation $\rho^\dagger$ by firm F of firm L's choice as well as the actual choice ρ by firm L (of course, in a pure-strategy equilibrium, $\rho^\dagger = \rho$).

Let $T_L(\rho, \rho^\dagger) \equiv \max_{a_L} \left\{\phi_L(a_L, a_F(\rho^\dagger)) - \psi(a_L, \rho) - C(\rho)\right\}$ denote player L's payoff when her actual investment is ρ and player F anticipates investment $\rho^\dagger$. The above assumptions imply that, whether SC or SS prevails, for all $(\rho, \rho^\dagger)$ and $(\hat{\rho}, \hat{\rho}^\dagger)$ with $\hat{\rho} \geq \rho$ and $\hat{\rho}^\dagger \geq \rho^\dagger$, the following "expectation conformity" condition is satisfied:

$$T_L(\hat{\rho}, \hat{\rho}^\dagger) - T_L(\rho, \hat{\rho}^\dagger) \geq T_L(\hat{\rho}, \rho^\dagger) - T_L(\rho, \rho^\dagger).$$

Consequently, let ρ (alternatively, $\hat{\rho}$) denote player L's optimal investment when player F expects investment $\rho^\dagger$ (alternatively, $\hat{\rho}^\dagger$).[11] Expectation conformity implies that there is complementarity between investment and anticipation of investment: $(\hat{\rho}_1 - \rho_1)(\hat{\rho}_1^\dagger - \rho_1^\dagger) \geq 0$. This is so both when the stage-2 game involves strategic substitutes or strategic complements.

The intuition goes as follows: Suppose that firm F expects L to invest more and therefore to produce more output. It then raises its output under SC and decreases it under SS. In either case, firm L is induced to raise its output, vindicating a higher investment in the first place. It can also be checked that when there are two equilibria ($\rho = \rho^\dagger$ and $\hat{\rho} = \hat{\rho}^\dagger$), player L is better off in the high-investment one, again regardless of the type of strategic interaction (SC or SS).

Let us draw a formal analogy between the generalized lemons game of the paper and the covert investment game described above. The investment ρ in the paper is player L's choice of a more informative signal. To interpret the generalized lemons game as a covert investment game, it suffices to assume that, in the "stage-2" game, player L wants to take an action equal to her investment. For example, one can think of a_L as the information used by player L in the stage-2 game. In this spirit, the assumption that L maximizes her payoff by choosing $a_L = \rho$ simply reflects the idea that player L makes full use of the acquired information. In this case, $\psi(a_L, \rho) = 0$ if $a_L = \rho$, whereas $\psi(a_L, \rho) = -\infty$ otherwise, which is a discontinuous version of the complementarity relationship

[10] See, e.g., Bulow et al (1985), and Fudenberg and Tirole (1984).

[11] That is, given $\rho^\dagger$, (a_L, ρ) is such that

$$(a_L, \rho) \in \arg\max_{\tilde{\rho}, \tilde{a}_L} \left\{\phi_L(\tilde{a}_L, a_F(\rho^\dagger)) - \psi_L(\tilde{a}_L, \tilde{\rho}) - C(\tilde{\rho})\right\}$$

with $\{a_L(\rho^\dagger), a_F(\rho^\dagger)\}$ denoting the Nash equilibrium of the normal-form game under common knowledge that L invested $\rho^\dagger$ (i.e., under symmetric information).

$\partial^2\psi_L/\partial a_L\partial\rho < 0$ in the investment game. Letting $a_F = r$, we then have that

$$\phi_L(a_L, r) \equiv \int_{-\infty}^{m^*(r)} \delta_L(m, r)dG(m; a_L)$$

and so $\partial^2\phi_L(r(\rho^\dagger), a_L)/\partial a_L\partial r < 0$ whenever condition $\mathrm{B}(\rho, \rho^\dagger) > 0$ in Proposition 1 in the main text is satisfied, for $a_L = \rho$. Furthermore, Condition $\mathrm{A}(\rho^\dagger) < 0$ in Proposition 1 implies that $dr/da_L < 0$. Summarizing, when the Condition of part (iv) of Proposition 1 is met, the lemons game can be seen as an investment game with strategic substitutes (SS). In contrast, many anti-lemon games are investment games with strategic complements.

S.4 Outer Game in Akerlof's Model with Flexible Information and Entropy Cost

In this section, we endogenize ρ in the Akerlof model with flexible information of Subsection 6.3 in the main text. We first show that the game with endogenous ρ also typically admits multiple equilibria. We then investigate whether the conditions for expectation conformity of Proposition 7 in the main text hold.

S.4.1 Multiple Equilibria in the Outer Game

Recall that the seller's payoff when she covertly chooses ρ, the buyer offers r, and the seller selects an arbitrary (binary) signal q and then engages for $z = 1$ and does not engage for $z = 0$ is equal to

$$\Pi(r, q; \rho) \equiv \int_\omega (r - \omega)q(1|\omega)dG(\omega) + \omega_0 - \frac{I^q}{\rho} - C(\rho). \tag{S.7}$$

Then let $\Pi^*(r, \rho) \equiv \Pi(r, q^{\rho,r}; \rho)$ denote the seller's maximal payoff when she responds to the buyer offering a price of r with a choice of ρ, where $q^{\rho,r}$ is the optimal signal given (ρ, r). As shown in the main text, the latter is given by

$$q^{\rho,r}(1|\omega) = \begin{cases} 0 \ \forall\omega \quad \text{if } r \leq \underline{r}(\rho) \\ \frac{1}{1+e^{\rho(\omega-\tilde{\omega}(r;\rho))}} \quad \text{if } r \in (\underline{r}(\rho), \overline{r}(\rho)) \\ 1 \ \forall\omega \quad \text{if } r \geq \overline{r}(\rho). \end{cases} \tag{S.8}$$

We use the Envelope Theorem to describe the seller's marginal value of investing in becoming a better learner (formally, in expanding ρ). Because $\Pi(r, q; \rho)$ is not Lipschitz continuous in ρ across all possible $(r, q; \rho)$, a little care is needed in establishing the result, which we provide in the following lemma.

Lemma S.1 (envelope theorem). *For any r, there exists $\overline{\rho}(r) > 0$ such that, for any $\rho > \overline{\rho}(r)$, any*

q, $\Pi(r,q;\rho) \leq \omega_0$, *whereas, for any* $\rho \leq \overline{\rho}(r)$, $\Pi^*(r,\rho)$ *is absolutely continuous in* ρ *with*

$$\frac{\partial \Pi^*(r,\rho)}{\partial \rho} = \frac{\partial \Pi(r,q^{\rho,r};\rho)}{\partial \rho} = \frac{I^{q^{\rho,r}}}{\rho^2} - C'(\rho) \tag{S.9}$$

for almost all $\rho \leq \overline{\rho}(r)$.

Proof of Lemma S.1. Fix r and note that the seller's gross payoff $\int_\omega (r-\omega) q(1|\omega) dG(\omega) + \omega_0$ from trading with the buyer is bounded from above by

$$\int_\omega (r-\omega)\mathbb{I}[\omega \leq r] dG(\omega) + \omega_0,$$

which is the seller's gross payoff under a signal that recommends to trade if and only if $\omega \leq r$ (hereafter, we refer to such a signal as "fully-responsive"). Because C is increasing and convex, $\lim_{\rho\to\infty} C(\rho) = +\infty$. Now let $\overline{\rho}(r)$ be defined by

$$\int_\omega (r-\omega)\mathbb{I}[\omega \leq r] dG(\omega) = C(\rho).$$

Clearly, for any $\rho > \overline{\rho}(r)$, any q,

$$\begin{aligned} \Pi(r,q;\rho) &= \int_\omega (r-\omega) q(1|\omega) dG(\omega) + \omega_0 - \tfrac{I^q}{\rho} - C(\rho) \\ &\leq \int_\omega (r-\omega)\mathbb{I}[\omega \leq r] dG(\omega) + \omega_0 - C(\rho) \\ &< \omega_0, \end{aligned}$$

which establishes that selecting ρ above $\overline{\rho}(r)$ is never optimal for the seller.

Next, let $\underline{\rho}(r)$ be the smallest value of ρ for which the inner problem admits an interior solution. For any $\rho < \underline{\rho}(r)$, the optimal signal $q^{\rho,r}$ entails no information acquisition and hence $I^{q^{\rho,r}} = 0$. This means that, for any $\rho < \underline{\rho}(r)$,

$$\Pi^*(r,\rho) \equiv \Pi(r,q^{\rho,r};\rho) = \omega_0 - C(\rho)$$

when the optimal signal prescribes never to sell and

$$\Pi^*(r,\rho) \equiv \Pi(r,q^{\rho,r};\rho) = r - C(\rho)$$

when it prescribes to sell for all possible ω. In either case, (S.9) holds.

Finally, consider $\rho \in [\underline{\rho}(r), \overline{\rho}(r)]$. Let $Q(r)$ denote the set of signals q for which $I^q \leq -\phi(G(r))$ and observe that this set includes the fully-responsive signal $q(1|\omega) = \mathbb{I}[\omega \leq r]$ for which the entropy cost is $I^q = -\phi(G(r))$. Clearly, for any $\rho \in [\underline{\rho}(r), \overline{\rho}(r)]$, and any $q \notin Q(r)$,

$$\Pi(r,q;\rho) < \int_\omega (r-\omega)\mathbb{I}[\omega \leq r] dG(\omega) + \omega_0 - \frac{-\phi(G(r))}{\rho} - C(\rho),$$

where the right-hand side is the seller's payoff under the fully-responsive signal $q(1|\omega) = \mathbb{I}[\omega \leq r]$.

For any $\rho \in [\underline{\rho}(r), \overline{\rho}(r)]$, the choice of q can thus be restricted to $Q(r)$. It is easy to see that, for any $\rho \in [\underline{\rho}(r), \overline{\rho}(r)]$, any $q \in Q(r)$, $\Pi(r, q; \rho)$ is differentiable in ρ with derivative uniformly bounded over $[\underline{\rho}(r), \overline{\rho}(r)] \times Q(r)$. That $\Pi^*(r, \rho)$ is absolutely continuous in ρ over $[\underline{\rho}(r), \overline{\rho}(r)]$ with derivative satisfying (S.9) then follows from Milgrom and Segal (2002). ■

Using the result in the lemma, for any r, the seller never chooses any $\rho > \overline{\rho}(r)$. Furthermore, when the optimal ρ is interior, the following optimality condition must hold

$$C'(\rho) = \frac{I^{q^{\rho,r}}}{\rho^2}.$$

This additional condition must be satisfied along with the conditions

$$\begin{cases} \tilde{\omega} = r + \frac{1}{\rho} \ln \left(\frac{\int \frac{1}{1+e^{\rho(\omega-\tilde{\omega})}} dG(\omega)}{1 - \int \frac{1}{1+e^{\rho(\omega-\tilde{\omega})}} dG(\omega)} \right), \\ r = \int \omega \frac{\frac{1}{1+e^{\rho(\omega-\tilde{\omega})}}}{\int \frac{1}{1+e^{\rho(\omega-\tilde{\omega})}} dG(\omega)} dG(\omega) + \Delta, \\ r \in (\underline{r}(\rho), \overline{r}(\rho)). \end{cases} \tag{S.10}$$

of the inner game in any equilibrium in the full game in which $\rho > 0$. As an illustration, suppose that ω is drawn from a uniform distribution over $[0, 1]$, $\Delta = 0.15$, and $C(\rho)$ is given by

$$C(\rho) = \begin{cases} \frac{a}{K} \frac{\rho^2}{2} & \text{if} \quad \rho \leq 10 \\ +\infty & \text{otherwise} \end{cases} \tag{S.11}$$

with $a \approx 1.46$ and $K = 1,000$. The reason for taking a very low value of a/K is that this guarantees an interior solution when the other parameters are as above. One can then show that the full game admits a unique equilibrium with information acquisition and, in such an equilibrium, $(\rho^*, r^*) \approx (4.7, 0.45)$.

Such an interior equilibrium coexists with an efficient equilibrium $(\rho_A, r_A) = (0, 0.65)$ in which the seller does not invest in learning how to process information ($\rho_A = 0$), acquires no information, and then sells with certainty at a price $r_A = \omega_0 + \Delta = 0.65$, and a market-breakdown equilibrium $(\rho_N, r_N) = (0, 0.15)$ in which the seller does not invest in learning how to process information ($\rho_N = 0$), acquires no information, and does not trade (in such an equilibrium, if the seller were to deviate and put the asset on sale, the buyer would offer $r_N = \Delta = 0.15$, with such a price supported by the belief that the seller learnt that the state is $\omega = 0$). Because the buyer breaks even in each equilibrium, the three equilibria are Pareto ranked, with the highest welfare attained in the equilibrium with full trade, and the lowest in the equilibrium with no trade—welfare in the equilibrium in which the seller invests in learning how to process information is in between the level of welfare in the two corner equilibria.

The game thus features a form of *expectation traps* between the two equilibria in which trade occurs with positive probability. When the buyer expects the seller to choose $\rho_A = 0$ and trade without acquiring information, she responds with a high price $r = r_A$ that gives a lot of surplus to the seller and induces the latter not to acquire any information. When, instead, the buyer expects the seller to invest ρ^* and then acquire information and trade selectively as a function of ω, she lowers her price to r^*, which forces the seller to acquire information and leaves her with a lower payoff.

S.4.2 Expectation Conformity

We conclude by investigating whether expectation conformity holds under this model specification. We do so by using Proposition 7 in the main text.

Recall that Proposition 7 assumes that Assumption 3 in the main text holds, which requires that, in the inner game, higher values of ρ are associated with higher equilibrium prices $r(\rho)$ if and only if higher values of ρ lead to an increase in the truncated mean:

$$\begin{aligned}\left.\frac{dr(\rho)}{d\rho}\right|_{\rho=\rho^\dagger} &\overset{\text{sgn}}{=} \left.\frac{\partial}{\partial\rho}M^-(m^*(r(\rho^\dagger));\rho,r(\rho^\dagger))\right|_{\rho=\rho^\dagger}\\ &= \left.\frac{\partial}{\partial\rho}\mathbb{E}[\omega|z=1;q^{\rho,r(\rho^\dagger)}]\right|_{\rho=\rho^\dagger}\\ &= \left.\frac{\partial}{\partial\rho}\int\omega\frac{q^{\rho,r(\rho^\dagger)}(1|\omega)}{q^{\rho,r(\rho^\dagger)}(1)}dG(\omega)\right|_{\rho=\rho^\dagger}.\end{aligned}$$

Under flexible information, for any $\rho>0$, the equilibrium price $r(\rho)$ is implicitly defined by the condition

$$r=\int\omega\frac{q^{\rho,r}(1|\omega)}{q^{\rho,r}(1)}dG(\omega)+\Delta. \tag{S.12}$$

Suppose again that ω is drawn from a uniform distribution over $[0,1]$ and that $\Delta=0.15$. One can then show that Assumption 3 holds for example when $\rho^\dagger=4.2,4.3,4.5,5$. Starting from these levels of ρ, a local increase in ρ leads to the choice of experiments resulting in a smaller truncated mean and to a reduction in the equilibrium price in the inner game. We can then use Proposition 7 in the main text to verify whether expectation conformity holds. We have already established that $\mathrm{A}(\rho^\dagger)<0$ for $\rho^\dagger=4.2,4.3,4.5,5$. Thus consider the function $B(\rho;\rho^\dagger)$. Fix some $\rho^\dagger$ and recall that

$$V^*(r,\rho)\equiv\int(r-\omega)q^{\rho,r}(1|\omega)dG(\omega)+\omega_0-\frac{I^{q^{\rho,r}}}{\rho}$$

is the seller's gross payoff under the optimal signal $q^{\rho,r}$. Using the envelope theorem

$$\frac{\partial V^*(r,\rho)}{\partial\rho}=\frac{I^{q^{\rho,r}}}{\rho^2}.$$

Recall that $B(\rho^\dagger;\rho^\dagger)$ measures how the marginal value $\partial V^*(r,\rho)/\partial\rho$ of the seller's investment in ρ changes with r, around $r=r(\rho^\dagger)$, when $\rho=\rho^\dagger$. Numerical results indicate that, in this example, $B(\rho^\dagger;\rho^\dagger)>0$ when $r(\rho^\dagger)>\omega_0=0.5$, whereas $B(\rho^\dagger;\rho^\dagger)<0$ when $r(\rho^\dagger)<\omega_0$. In other words, when $r(\rho^\dagger)>\omega_0$, a local reduction in r around $r(\rho^\dagger)$ increases the marginal value of ρ around $\rho^\dagger$, whereas the opposite is true when $r(\rho^\dagger) < \omega_0$. These results indicate that the marginal value of information $\partial V^*(r,\rho)/\partial\rho$ is single-peaked at $r = \omega_0$, as illustrated in Figure 1.

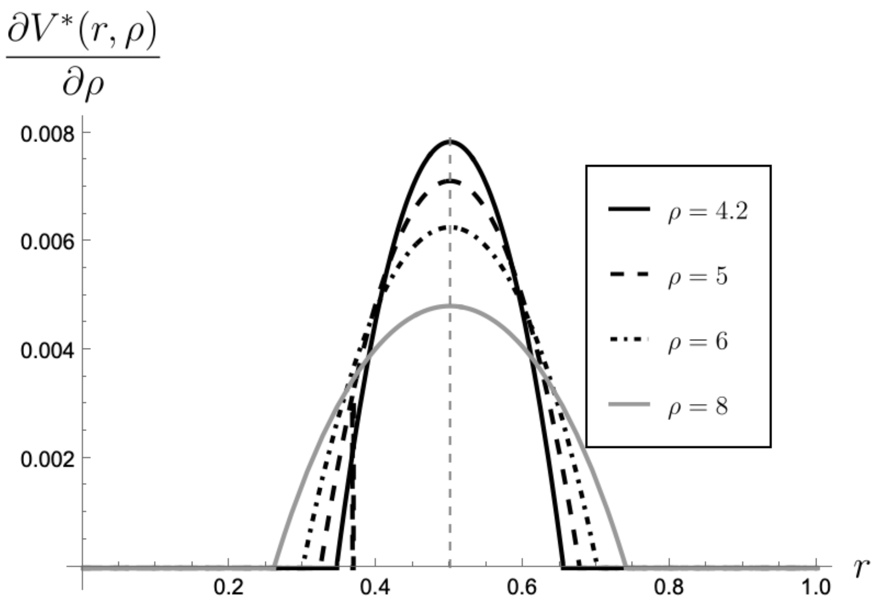

Figure 1: Effects of changes in r on $\partial V^*(r,\rho)/\partial\rho$ for different values of ρ, when $\omega \sim U[0,1]$.

Recall that Part (i) of Proposition 7 establishes that expectation conformity holds at $\rho = \rho^\dagger$ if $\mathrm{A}(\rho^\dagger)$ and $B(\rho^\dagger;\rho^\dagger)$ have opposite signs. In this example, this happens when $\rho = \rho^\dagger = 4.2$ and $\rho = \rho^\dagger = 4.3$ but not when $\rho = \rho^\dagger = 4.5$ and $\rho = \rho^\dagger = 5$.

Part (*ii*) of Proposition 7 in turn establishes that a sufficient condition for an increase in ρ to aggravate adverse selection at $\rho = \rho^\dagger$ (that is, for $\mathrm{A}(\rho^\dagger) < 0$) is that $q^{\rho,r(\rho^\dagger)}(1|\omega)/q^{\rho,r(\rho^\dagger)}(1)$ is increasing in ρ for $\omega < r(\rho^\dagger)$ and decreasing in ρ for $\omega > r(\rho^\dagger)$ at $\rho = \rho^\dagger$. These properties hold in the example under consideration for $\rho^\dagger = 4.2, 4.3, 4.5, 5$.

Finally, Part (iii) of Proposition 7 establishes that a sufficient condition for a reduction in r around $r(\rho^\dagger)$ to raise L's marginal value of ρ at $\rho = \rho^\dagger$ (i.e., for $B(\rho^\dagger;\rho^\dagger) > 0$) is that, in addition to $q^{\rho,r(\rho^\dagger)}(1|\omega)/q^{\rho,r(\rho^\dagger)}(1)$ to be increasing in ρ at $\rho = \rho^\dagger$ for $\omega < r(\rho^\dagger)$ and decreasing in ρ at $\rho = \rho^\dagger$ for $\omega > r(\rho^\dagger)$, the total probability $q^{\rho,r(\rho^\dagger)}(1) \equiv \int q^{\rho,r(\rho^\dagger)}(1|\omega)dG(\omega)$ the seller puts the asset on sale is non-increasing in ρ at $\rho = \rho^\dagger$. The numerical simulations show that, in the example under consideration, the total probability $q^{\rho,r}(1)$ the seller puts the asset on sale is increasing in ρ when $r < \omega_0$ and decreasing in ρ when $r > \omega_0$. Part (iii) of Proposition 9 then implies that, when $\rho^\dagger$ is such that $r(\rho^\dagger) > \omega_0$, $B(\rho^\dagger;\rho^\dagger) > 0$. When, instead, $\rho^\dagger$ is such that $r(\rho^\dagger) < \omega_0$, because part (iii) of Proposition 9 provides only sufficient conditions for $B(\rho^\dagger;\rho^\dagger) > 0$, we cannot conclude from the above monotonicity that $B(\rho^\dagger;\rho^\dagger) < 0$ at $\rho = \rho^\dagger$. However, because in the Akerlof model $\partial^2\delta_L(r,m)/\partial r\partial m = 0$, and because $M^-(m^*(r(\rho^\dagger));\rho, r(\rho^\dagger))$ is decreasing in ρ at $\rho = \rho^\dagger = 4.5, 5$ (as shown above), part (v) in Proposition 7 implies that, when $\rho^\dagger = 4.5, 5$, because $\mathrm{A}(\rho^\dagger) < 0$ and $q^{\rho,r}(1)$ is increasing in ρ at $(\rho, r) = (\rho^\dagger, r(\rho^\dagger))$, expectation conformity does not obtain at $(\rho,\rho^\dagger) = (4.5, 4.5)$ and $(\rho,\rho^\dagger) = (5, 5)$.

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