Accounting Information and Risk Shifting with Asymmetrically Informed Creditors

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Abstract

This paper explores the effects of public information (e.g., accounting earnings) in a competitive lending setting where the borrower can engage in risk shifting. If a privately informed "inside" creditor bids against outsider creditors, public information levels the playing field with nontrivial effects on bidding and risk-shifting. A perfect public signal would yield the least efficient outcome: introducing some measurement noise alleviates risk shifting by subjecting the outsider to the winner's curse. However, for pessimistic priors about the borrower, greater precision can alleviate risk shifting, locally. We derive conditions under which greater signal precision lowers the probability of creditor turnover and discuss implications for financial reporting regulations along the business cycle.

Keywords: Asset substitution, relationship lending, creditor turnover, accounting information
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1 Introduction

A growing literature has documented the usefulness of public accounting information for debt contracting.[1] Creditors who lack private information about borrowers must rely on public information to make lending decisions. However, lending interactions are typically dynamic in nature, in that a given bank lends repeatedly to the same borrower. In the course of such relationship lending, the (incumbent) bank acquires private information about the creditworthiness ("state") of the borrower.[2] As a result, any competition for future lending takes place under asymmetric information, with the incumbent enjoying an informational advantage. Public information tends to level the playing field between potential creditors at this stage. In this paper, we ask how the precision of such public information affects the competition among creditors, the borrower's incentive to engage in risk shifting, and the stability of the lending relationship (creditor switching).

Debt introduces convexity into the payoff for the borrower and hence may induce excessive risk taking, causing asset substitution problems. Creditors anticipate and seek ways to protect against such opportunistic behavior. Many forms of risk shifting—e.g., the choice of R&D projects, the structure of supply chain contracts—are non-contractible and often even unobservable to creditors. Thus the pricing of debt and nonparticipation in lending are important ways to protect against a borrower's (conjectured) risk shifting.[3] Moreover, the borrower's risk choice typically varies with his state, as the risk shifting incentive tends to be more severe in bad states of the world where shareholders (creditors) become residual claimants mostly for the upside (downside). Thus, although no creditor directly observes the borrower's risk choice, in equilibrium, an inside creditor who has private information about

[1]See Armstrong et al. (2010) and Christensen et al. (2016) for detailed reviews of the recent literature.

[2]Diamond (1984), Ramakrishnan and Thakor (1984), Boyd and Prescott (1986), Rajan (1992), Petersen and Rajan (1994).

[3]Armstrong et al. (2010, p.213): "It is much more difficult to design a contractual mechanism based on accounting information that will force firms to commit to invest in all positive NPV projects or to maintain a given risk profile when exercising future growth options. Thus, lenders must rely on other contractual mechanisms, such as price protection through interest rates ... to reduce these costs."

the borrower's *state* is also better informed about the borrower's *action* (risk shifting) than outside creditors. Consequently, public information levels the playing field among creditors in more than one way.

To study the effect of public information on the borrower's risk taking behavior, we embed an unobservable state-contingent risk choice into a two-period lending model with asymmetrically informed creditors in the presence of a public signal about the borrower's state. In our model, the firm invests in a project in each period, financed through debt in a competitive lending market. The period-1 project is safe and has zero NPV; it allows the firm and the initial creditor to learn the firm state at the end of the first period. The second-period project is risky: its return depends on the firm state and a project risk choice privately made by the firm, which determines the risk-return tradeoff. The informed inside creditor and a representative outside creditor, who only observes the public signal, compete for second-period lending. A higher return to a successful project in the good state dampens the firm's risk shifting incentive, as the debt-induced call option is more "in the money." Our model thus focuses on risk shifting in the bad state, in line with much of the empirical evidence (Eisdorfer 2008).

The bidding competition in the second period unfolds in the form of a standard first-price common-value auction,[4] which we augment with an endogenous risk choice. The outside creditor is informationally handicapped: not knowing the true state, his bids are based only on (noisy) public information. Given any conjectured risk choice, there exists a mixed-strategy equilibrium in which the outside creditor actively participates in the bidding with probability strictly less than one, so as to protect against the winner's curse. The inside creditor, knowing the true state, always bids the break-even face value upon a bad state; upon a good state, he randomizes his bids over the same support as does the outsider. As a result, the inside creditor earns information rents in the second period, whereas the outside creditor just breaks even, losing in the bad state what he gains in the good state, in

[4]E.g., Engelbrecht-Wiggans et al.(1983), Rajan (1992), etc.

expectation.

How does public information precision affect the lending competition and the borrower's risk-taking? In a benchmark setting with symmetric but imperfect public information (i.e., no creditor learns the firm state), greater information precision always exacerbates the risk-shifting incentive by increasing the face value of debt in the bad state. A perfect public signal would therefore create the most extreme risk shifting problem.

The result that a perfect public signal yields the least efficient outcome carries over to the main model with asymmetrically informed creditors. But unlike the symmetric information benchmark, increasing information precision is not always harmful, at the margin: a *local* increase in precision may *alleviate* risk shifting if the prior about the firm's state is sufficiently pessimistic. Key to this result is the manner in which information precision affects the updating process on the part of the outside creditor. If a good firm state is unlikely ex ante, then an increase in precision has only a muted updating effect conditional on a bad signal realization (the signal merely confirms the prior) but a strong updating effect conditional on a good realization. Thus, the outsider will bid somewhat more conservatively upon observing a bad signal, but much more aggressively upon observing a good signal. This asymmetry in the updating process, as public information becomes more precise, implies a reduction in the expected face value of debt in the bad firm state for pessimistic priors, which in turn alleviates the firm's risk shifting incentive. This result is in line with Doblas-Madrid and Minetti (2013) who found that information sharing among creditors through PayNet reduces borrower risk and defaults, especially for small and young firms (arguably subject to less favorable priors). Converse arguments apply to optimistic priors about the firm's state: more precise public information then tends to exacerbate the asset substitution problem.

These results have implications for financial reporting regulation along the business cycle. Our model suggests that improving financial reporting precision tends to alleviate the asset substitution problem in times of economic downturn but exacerbates it in boom times. In practice, however, regulators often display a tendency to relax financial reporting stringency during economic downturns and to tighten it during boom periods (Bertomeu and Magee, 2011). As our paper shows, such pro-cyclical regulations may adversely affect the economy by inducing excessive risk-taking.

A recurring theme in the literature is the winner's curse that creditors are facing when bidding against better informed rivals (e.g., von Thadden 2004). It is instructive to view through this lens our result that a perfect public signal maximizes distortions. Adding some degree of measurement error to a perfect public signal introduces winner's curse concerns for the outside bidder. Ex ante, in expectation over firm states, this increases the expected face value of debt, because of the strategic nonparticipation and price protection on the part of the outsider (and the insider's optimal response). But conditional on a bad state realization, measurement error *decreases* the expected face value of debt—it is here where the winner's curse hits and where risk shifting occurs. Introducing a winner's curse therefore alleviates risk shifting. This stands in stark contrast to Rajan's (1992) model without a state-contingent risk choice, in which a perfect public signal maximizes efficiency.

We also examine the impact of public information precision on the stability of lending relationships. With public signals leveling the playing field, one might conjecture that more precise such signals should make creditor turnover more likely. However, the above discussion shows that the effect of public information on expected bidding outcomes can be subtle. In fact, we find that the same condition that predicts a negative relation between signal precision and risk shifting in bad firm states—a pessimistic prior about the firm's prospects—also predicts a negative relation between precision and the probability of creditor turnover. More precise public information makes creditor turnover more likely in good firm states and less likely in bad states, because it alleviates the outsider's winner's curse problem. We show that the negative effect associated with bad firm states tends to be the dominant one from an ex ante perspective, provided increased precision alleviates the risk shifting problem (which it does for pessimistic priors, as just discussed).

Public information in our model can emanate from many different sources, such as credit reports, media coverage, analysts reports, and firm's financial reporting etc. Much research in the accounting literature which has focused on accounting-based covenants as means for providing creditor protection, e.g., by restricting dividend payments or the issuance of senior debt. But in competitive loan markets where outsiders may suffer the winner's curse when lending to the borrower, accounting information is arguably the most important source of public information for creditors without private access to the borrower. Our paper sheds light on the usefulness of accounting information in settings where public information adds little incremental value to informed creditors (Armstrong et al., 2010), but is a primary source of information for outside creditors.

Our paper relates to theoretical studies that examine the role of accounting information in mitigating agency conflicts between debt- and equity-holders. Lu et al. (2016) show that regulations based on market prices can alleviate asset substitution problems, at the cost of exacerbating debt overhang problems. Li (2017) studies the link between accounting measurement rules and banks' risk-taking incentives if banks rely on deposit financing and are subject to capital regulation: a lower-of-cost-or-equity regime then may mitigate the risk-taking incentive. Burkhart and Strausz (2009) find that fair value accounting exacerbates the risk-shifting problem by increasing the liquidity of banks' assets. Corona et al. (2015) study the interaction between inter-bank competition, accounting information quality, and banks' risk-taking behavior: they show that improving information quality increases risk-taking with mild competition, but has no effect with fierce competition. Han (2018) studies how accounting precision affects investment efficiency and risk-shifting incentives in a setting with a single creditor who faces both cash-diversion and asset-substitution problems. Our paper, in contrast, focuses on the way public information levels the playing field among asymmetrically informed creditors, and the consequences for risk-shifting.

This paper also contributes to the research on the costs and benefits of relationship lending. A common refrain in the literature is that ongoing lending relationships can mitigate information frictions, especially if borrowers cannot credibly reveal their investment profitability through public communication and have limited access to capital markets (Boot, 2000; Boot and Thakor 1994; Peterson and Rajan 1994). But relationship lending also imposes costs on borrowers, e.g., through rent extraction and hold-up problems (Sharpe 1990; Rajan 1992; Petersen and Rajan 1995). Our results highlight another cost of relationship lending: for given public information precision, we show that if an insider becomes perfectly informed about the firm's bad state, the firm engages in more risk shifting.

The remainder of the paper is organized as follows. Section 2 lays out the basic model. Section 3 analyzes optimal debt contracts with symmetric information, as a benchmark. Section 4 introduces an inside creditor who has an information advantage when competing with an outside creditor. Section 5 studies the effect of public information on risk taking and Section 6 that on creditor turnover. Section 7 concludes. All proofs are relegated to the Appendix.

2 The Model

Consider a two-period model where a risk-neutral firm (borrower) needs to raise capital from risk-neutral creditors to undertake a project in each period.[5] Each project requires an equal amount of investment K, without loss of generality. We ignore any discounting. The first-period project is a safe, zero-NPV investment that always generates a cash flow of K. We include the first-period project in the model to allow for a channel—i.e., relationship lending—through which an "inside" creditor becomes informed about the firm. The second-period project is risky: its return depends on the firm state realized at the end of period 1 and the firm's risk choice, which we will explain in detail below. The firm and the inside creditor jointly observe the firm state, $\mu \in \{\mu_G, \mu_B\},\ \mu_G > \mu_B > 0$. The ex ante probability that the firm is in the good state is $\pi = \Pr(\mu = \mu_G),\ 0 < \pi < 1$.

The project technology. The firm's risk choice for the second-period project is made

[5]We focus the analysis on debt financing and assume away issues related to capital structure and security design.

privately by the firm, non-contractible, and described by $p \in (0, 1]$.[6] Specifically, for a given state μ, the project succeeds with probability p, in which case it generates a cash flow of $R(p, \mu)$; otherwise, the project fails with zero cash flow. The cash flow $R(p, \mu)$ in case of success is decreasing in the success probability p and increasing in the state μ_i, in that

$$R(p, \mu) = -r \ln(p) + \mu,$$

where $r > 0$ parameterizes the marginal impact of the risk choice on the cash flow of a successful project—and thereby the "slope" of the risk-return trade-off. Thus, the project's expected (net present) value is given by

$$V(p, \mu) = p \cdot R(p, \mu) - K.$$

As will become clear soon, with debt financing, this risk-return trade-off is the source of borrower-creditor conflict of interests. The risk-return tradeoff is also the main departure from earlier relationship-lending models such as Rajan (1992).[7]

The debt market is competitive ex-ante. At date 0, the firm signs a debt contract with a creditor, which stipulates initial funding for the first-period investment K and a debt repayment of D_1 at date 1. At date 1, the firm pays back the first-period debt and seeks financing of the same amount K for the second-period project. Denoting the face value of the second-stage debt contract by D_2, the firm's payoff in expectation over a second-period project outcome is

$$U = K - D_1 + p(R(\cdot) - \min\{D_2, R(\cdot)\}). \tag{1}$$

We impose the following maintained assumption about the firm state:

[6] We assume that the *ex-post* project cash flow R is non-contractible. Because the cash flow is contingent on the true project state, conceptually it can be used in debt contracting to alleviate information asymmetry between the creditor and the firm. While this outcome-contingent mechanism is useful, it is not common in debt contracting in practice: debt repayments do not fluctuate with a firm's final cash flows (other than in the case of default). Debt repayments are typically fixed throughout the life of debt contracts. Moreover, the project cash flows could be very volatile or non-verifiable, making it non-contractible.

[7] In Rajan (1992), the borrower takes a value-increasing effort upfront that is not state-contingent and increases the probability of a project success without affecting the cash flow conditional on success.

Assumption 1 $\mu_B < K < r$ *and* $\mu_G > \underline{\mu}_G > r + K$.

Assumption 1 implies that, if the firm were to choose a completely safe second-period project, i.e., $p = 1$, the project NPV would be positive and sufficiently high in the good state μ_G, but negative in the bad state μ_B. We will show later that this assumption ensures the firm has no incentive to take any risk in the good state, which allows us to focus on analyzing the firm's risk-taking incentive in the bad state (Eisdorfer 2008).[8] This greatly facilitates the tractability of the model and sharpens the insights.

Public accounting information. The inside creditor, like the firm itself, observes the firm state perfectly and competes with an outside creditor for second-period financing.[9] The outside creditor does not learn the true state and observes only a noisy public signal about the state, denoted by $\phi \in \{\phi_g, \phi_b\}$, where $\Pr(\phi_g|\mu_G) = \Pr(\phi_b|\mu_B) = q \in [\frac{1}{2}, 1]$ represents the quality of public information. One important source of such public information is, of course, reported accounting earnings.[10] If $q = 1/2$, the signal is completely uninformative; if $q = 1$, it perfectly reveals the firm state. Denote by $\Pr(\mu|\phi)$ the outside creditor's updated belief about the state μ given the observed signal ϕ:

$$\Pr(\mu_G|\phi_g) = \frac{\pi q}{\pi q + (1-\pi)(1-q)} \quad \text{and} \quad \Pr(\mu_B|\phi_b) = \frac{(1-\pi)q}{\pi(1-q) + (1-\pi)q}. \tag{2}$$

The competitive bidding process. The inside (I) and outside (O) creditors each submit a bid specifying a debt repayment amount at date 2 when the project's cash flows are realized. Denote creditor j's information set at the bidding stage by Ω^j, where $\Omega^O = \{\phi\} \subset \Omega^I = \{\mu, \phi\}$. The inside creditor's bid $D^I(\mu, \phi)$ is conditioned on the firm state μ and the public signal ϕ; the outside creditor's bid $D^O(\phi)$, only on the public signal ϕ. The firm

[8] In the Appendix we present a closed-form expression for the threshold $\underline{\mu}_G$, in Assumption 1.

[9] In our model, the first-period lending is an essential stage of investment whereby the firm can discover the investment opportunity and invest in the second-stage project. During the course of the first-period lending, the engaged (incumbent) creditor inevitably becomes more informed about the firm's operations and performance than an outside creditor, leading to asymmetric bidding in the second period.

[10] We assume that the public signal provides information about the firm's state, rather than the expected cash flow $R(p_i, \mu_i)$. Interpreting the public signal as reported accounting earnings, this is consistent with the current financial reporting framework that most accounting information captures past transactions and performance, rather than providing forward-looking information of cash flows to be realized.

accepts the lowest bid, $D_2 = \min\{D^O(\phi), D^I(\mu,\phi)\}$, and carries out the project. At date 2, if the project succeeds, the cash flow $R(p,\mu)$ is realized, and the firm pays $\min\{D_2, R\}$ to the winning creditor; otherwise, the project fails, and the creditor receives the liquidation value, which is normalized to zero. We assume the standard tie-breaking rule that a coin toss determines the winner, if both creditors submit the same bid.[11]

The expected period-2 payoff for creditor k, denoted Π_2^k, is

$$\Pi_2^k = \begin{cases} 0, & \text{if he loses the auction} \\ p \cdot \min\{D_2, R(\cdot)\} - K, & \text{if he wins the auction} \end{cases}, \quad k \in \{I, O\}.$$

Upfront, the inside creditor's expected payoff (the outsider is not present in the first period yet) is

$$\Pi_1^I = D_1 - K + E[\Pi_2^I]$$

In the first period, all players rationally anticipate the inside creditor's expected future information rent, $E[\Pi_2^I]$. Given the competitive debt market, the creditor who lends in the first period breaks even *ex-ante*. Credit market competition allows the borrower to extract this expected rent upfront; hence the first-period debt face value is given by:

$$D_1 = K - E[\Pi_2^I]. \tag{3}$$

The timeline.

- *Date 0:* The firm invests in a project and signs a short-term debt contract with a creditor that stipulates funding K and a debt repayment at date 1, D_1, as in (3).
- *Date 1*: The state $\mu \in \{\mu_G, \mu_B\}$ is realized. The firm observes the state perfectly and privately makes the project risk choice p.

[11] In our model, the tie-breaking rule is irrelevant for the expected debt repayment, and thus does not affect the firm's risk choice. But it matters for the creditor turnover probability. Alternatively one could assume a tie-breaking rule that favors the inside creditor (Rajan 1992 and von Thadden 2001), e.g., because of transaction costs of switching. In Section 6, we will discuss the effect of this alternative tie-breaking rule on creditor turnover.

- *Date 2:* The firm seeks financing for the second-period project by inviting competitive bids from both the inside and outside creditors. The inside creditor observes the true state μ. Both creditors observe the public signal $\phi \in \{\phi_g, \phi_b\}$. The inside creditor submits a bid D^I and the outside creditor submits a bid D^O. The firm accepts the lower of the two bids, $D_2 = \min\{D^O, D^I\}$.

- *Date 3:* If the project succeeds, the project cash flow $R(p, \mu_i)$ is realized and the firm pays $\min\{D_2, R\}$ to the winning creditor; otherwise, cash flow and payments are zero.

3 Benchmark Cases

3.1 First-Best Case

We first consider the first-best case where the firm has sufficient internal capital to fund the project in both stages and does not require any external financing. Such a setting is equivalent to a debt financing setting in which the project choice is contractible. Having observed the firm state μ, the firm chooses $p \in [0, 1]$ to maximize the total expected return $V(p, \mu)$. The first order condition is given by

$$\frac{\partial V(p, \mu)}{\partial p} = R(p, \mu) - r = 0. \tag{4}$$

An interior solution to this first-order condition is described by $p_i = \exp[\mu_i/r - 1]$.[12] Given Assumption 1, however, this interior solution applies only in the bad firm state, whereas the first-best choice in the good state is a perfectly safe project (a corner solution):

Lemma 1 *Without debt financing, the first-best risk choice is risk-free in the good state, and described by an interior solution in the bad state:* $p_G^{fb} = 1 > p_B^{fb} = \exp[\mu_B/r - 1]$.

Substituting p_G^{fb} and p_B^{fb} into the project's return function, we obtain the firm's expected payoff from the second period project:

$$V(p_G^{fb}, \mu_G) = \mu_G - K, \text{ and } V(p_B^{fb}, \mu_B) = r \cdot \exp\left[\frac{\mu_B}{r} - 1\right] - K. \tag{5}$$

[12]The second order condition is satisfied $\partial^2 V(p, \mu/\partial p^2 < 0$. Thus p_i^{fb} is a global maximum point.

The project's expected return in the bad state increases with r, i.e., $dV(p_B^{fb}, \mu_B)/dr > 0$. Thus, for r sufficiently large, the project's NPV in the bad state is always positive for a risk choice of $p_B^{fb} < 1$. In what follows, we implicitly assume that r is sufficiently large, so that it is profitable to invest in the bad state. Given the firm's first-best risk choices in Lemma 1, the firm's first-best expected payoff, ex-ante, is

$$V^{fb} = \pi V(\mu_G, p_G^{fb}) + (1-\pi)V(\mu_B, p_B^{fb}) = \pi\mu_G + (1-\pi)rp_B^{fb} - K. \tag{6}$$

3.2 Symmetrically Informed Creditors with Noisy Public Signals

Another relevant benchmark is the case with symmetrically informed creditors. Suppose the firm requires external financing, the technology choice is neither contractible nor observable, and the firm's state is observable only to the firm. Any potential creditor observes only the noisy public signal. Lending competition in the second-period then takes place under symmetric information among the potential creditors: the creditors can condition their bids only on the public signal, ϕ, and the conjectured project choices, $\hat{\mathbf{p}}^n = (\hat{p}_G^n, \hat{p}_B^n)$. Bertrand competition drives down the bids for the face value of debt to the breakeven amounts given by

$$\begin{aligned} &\hat{p}_G^n Pr(\mu_G|\phi_j) D_j(\hat{\mathbf{p}}^n) + \hat{p}_B^n Pr(\mu_B|\phi_j) D_j(\hat{\mathbf{p}}^n) - K = 0, \\ \Rightarrow \quad & D_j(\hat{\mathbf{p}}^n) = \frac{K}{\hat{p}_G^n Pr(\mu_G|\phi_j) + \hat{p}_B^n Pr(\mu_B|\phi_j)}. \end{aligned} \tag{7}$$

Assumption 1 again ensures that the firm's optimal risk choice is given by a perfectly safe project in the good firm state, $\hat{p}_G^n = p_G^n = 1$. Given the firm's payoff function in (1) and the conjectured risk choice $\hat{\mathbf{p}^{\mathbf{n}}}$, in the bad state, the firm selects the risk choice p_B according to the first-order condition

$$R(p_B^n, \mu_B) - r - E[D_2^n \mid \mu_B, \hat{\mathbf{p}}^n] = 0, \tag{8}$$

where $E[D_2^n \mid \mu_B, \hat{\mathbf{p}}^n] = qD_b(\hat{\mathbf{p}}^n) + (1-q)D_g(\hat{\mathbf{p}}^n)$ is the expected debt repayment at date 2 in the bad state for any conjectured choices. Because in equilibrium, conjectures must be correct, i.e., $p_j^n = \hat{p}_j^n$, the optimal project choice satisfies the implicit condition:

$$R(p_B^n, \mu_B) - r - E[D_2^n \mid \mu_B, p_G^n = 1, p_B^n] = 0. \tag{9}$$

Proposition 1 *With only the noisy public signal (i.e., no creditor learns the firm's state), the firm's project choice in the good state is risk free, $p_G^n = p_G^{fb} = 1$; the project choice in the bad state, described by (9), is riskier than the first-best level, $p_B^n < p_B^{fb}$ for any q, and becomes even riskier as the precision of the public signal increases, $dp_B^n/dq < 0$.*

A standard asset substitution problem pushes the borrower to take on more risk than in the first-best benchmark where the firm needs no external funding. Debt financing introduces a call option (convexity) into the firm's objective function. As a result, whenever a risk choice is described by an interior solution, as is the case in the bad state, debt will result in excessive risk-taking. Regarding the second part of the result, as the public signal becomes more informative, the bad state will be revealed more precisely to the creditors, resulting in a higher expected breakeven face value of debt. This in turn pushes the borrower's call option further out of the money in the bad state, aggravating the risk-shifting incentive.

Because in this benchmark setting all potential creditors just break even in any period, the firm extracts the total surplus in expectation. Thus the sub-optimal choice of project risk always reduces the firm's expected payoff—a classic lack of commitment problem.

4 Asymmetrically Informed Creditors

In this section, we turn to the main model in which creditors are asymmetrically informed about the firm state. After observing the state, the firm seeks period-two debt financing from the inside (incumbent) creditor or from a representative outside creditor. As described above, the inside creditor becomes perfectly informed about the firm state in the course of first-stage lending, whereas the outside creditor observes only the noisy public signal about the states. Both creditors submit bids for the face value of period-two debt. We allow for mixed bidding strategies: for given state μ_i and public signal ϕ_j, the inside creditor may randomize his bid D^I according to the probability distribution H^I_{ij}, whereas the outside creditor may randomize his bid D^O according to the probability distribution H^O_j. The firm accepts the lower of the two bids, i.e., $D_2 = \min\{D^I, D^O\}$.

To formally define a Perfect Bayesian Equilibrium with asymmetrically informed creditors, we write $E[D_2 \mid \mu_i, \phi_j, \hat{\mathbf{p}}]$ for the expected face value resulting from the date-2 bidding game, conditional on the state μ_i, the public signal ϕ_j, and the risk conjectures $\hat{\mathbf{p}} = (\hat{p}_G, \hat{p}_B)$, which yields

$$E[D_2 \mid \mu_i, \hat{\mathbf{p}}] = \Pr(\phi_g \mid \mu_i) E[D_2 \mid \mu_i, \phi_g, \hat{\mathbf{p}}] + \Pr(\phi_b \mid \mu_i) E[D_2 \mid \mu_i, \phi_b, \hat{\mathbf{p}}],$$

for the face value in expectation over the public signal. Lastly, let $U(p_i, \mu_i, \hat{\mathbf{p}}) \equiv p_i[R(p_i, \mu_i) - E[D_2|\mu_i, \hat{\mathbf{p}}]]$ denote the borrower's payoff.

Definition 1 *An equilibrium consists of the firm's risk choices $\{p_G(\cdot), p_B(\cdot)\}$, the inside creditor's bidding strategy $H^I_{ij}(\cdot)$, and the outsider creditor's bidding strategy $H^O_j(\cdot)$, such that:*

1. *At date 1, after observing the state $\mu_i \in \{\mu_G, \mu_B\}$, the firm chooses $p_i \in [0,1]$ to maximize its expected payoff, given the creditors' conjecture $\hat{\mathbf{p}}$, i.e.,*

$$p_i = \arg\max_p U(p, \mu_i, \hat{\mathbf{p}}).$$

2. *At date 2, the inside creditor, having observed the state μ_i and the public signal ϕ_j, bids according to the strategy $H^I_{ij}(\cdot)$ so as to maximize $E[\Pi^I_2(\cdot) \mid H^O_i(\cdot), \hat{\mathbf{p}}, \mu_i, \phi_j]$; the outside creditor, having observed the public signal ϕ_j, bids according to the strategy $H^O(\cdot)$ so as to maximize $E[\Pi^O_2(\cdot) \mid H^I_{ij}(\cdot), \hat{\mathbf{p}}, \phi_j]$.*

3. *The creditors' conjectures are correct, i.e., $\hat{p}_G = p_G$ and $\hat{p}_B = p_B$.*

4.1 The Bidding Game

We first determine the creditors' bidding strategies at the second stage before solving for the full equilibrium. The bidding game is a standard first-price common-value auction with asymmetrically informed bidders, in which both creditors submit sealed bids for the debt repayment, given the conjectured risk choices $\hat{\mathbf{p}}$.

It is a well-known result that no pure-strategy equilibrium exists in such an auction setting with asymmetrically informed bidders (Engelbrecht-Wiggans, Milgrom and Weber, 1983; Rajan, 1992; von Thadden, 2001). If the outside bidder were to bid according to a pure strategy, he would incur a loss in expectation, because the informed creditor could always undercut the (deterministic) bid by a small amount upon observing a good state, and not bid upon observing a bad state. As a result, the outside creditor will "win" the bid only in the bad state—an extreme form of the winner's curse. Therefore, both creditors will adopt a mixed strategy in equilibrium.

Proposition 2 *Given the state μ_i, the public signal ϕ_j, and the conjectured risk choice $(\hat{\mathbf{p}})$, there exists a mixed-strategy bidding equilibrium as follows, where $D_G(\hat{p}_G) = K/\hat{p}_G$, $D_B(\hat{p}_B) = K/\hat{p}_B$, and $D_j(\hat{\mathbf{p}}) = K/[\hat{p}_G Pr(\mu_G|\phi_j) + \hat{p}_B Pr(\mu_B|\phi_j)]$:*

1. *The outside creditor mixes his bids over the range $[D_j(\hat{\mathbf{p}}), D_B(\hat{p}_B))$ according to the distribution $H_j^O(D, \hat{\mathbf{p}}) = \frac{D - D_j(\hat{\mathbf{p}})}{D - D_G(\hat{p}_G)}$, and bids $D_B(\hat{p}_B)$ with probability of $1 - \Phi_j$, where $\Phi_j \equiv H_j^O(D_B) = \frac{D_B(\hat{p}_B) - D_j(\hat{\mathbf{p}})}{D_B(\hat{p}_B) - D_G(\hat{p}_G)}$.*

2. *The inside creditor bids $D_B(\hat{p}_B)$ with probability 1 upon observing the bad state μ_B; upon observing the good state μ_G (and a public signal ϕ_j), the inside creditor mixes his bids over the range $[D_j(\hat{\mathbf{p}}), D_B(\hat{p}_B)]$, according to the distribution $H_{Gj}^I(D) = \frac{1}{\Phi_j} H_j^O(D)$.*

The detailed proof of Proposition 2 is provided in the Appendix; it closely follows Rajan (1992) and von Thadden (2001). To avoid clutter, whenever there is no scope for confusion, we write D_j, D_B and Φ_j, suppressing the arguments $\hat{p}_j$.

Creditors' realized payoffs. In equilibrium, the inside creditor's bidding strategy $H_{ij}^I(\cdot)$ is a nontrivial function of the public signal not because he learns from ϕ_j about the state μ_i (he has learned the state in the course of prior lending), but because he optimizes against the outside bidder whose strategy $H_j^O(\cdot)$ is conditioned only on ϕ_j.

We begin with the outside creditor. Having observed only the public signal, ϕ_j, the outside creditor's expected payoff, conditional on ϕ_j and a submitted bid D, is

$$\Pi_j^O(D) = \Pr(\mu_G|\phi_j)(1 - H_{Gj}^I(D))\hat{p}_G(D - D_G) + \Pr(\mu_B|\phi_j)(1 - H_{Bj}^I(D))\hat{p}_B(D - D_B).$$

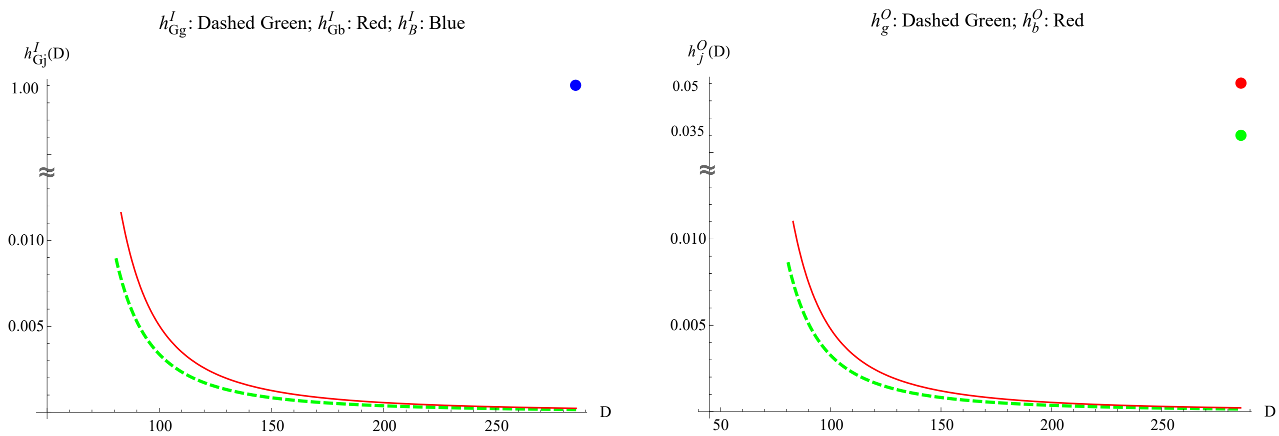
With probability $\Pr(\mu_G|\phi_j)$, the outside creditor believes that the state is good and expects the insider to mix his bid according to the strategy $H_{Gj}^I(\cdot)$. Hence, taking as given the risk choice conjecture, the outside creditor expects to win the auction and realize a payoff of $\hat{p}_G(D-D_G)$, whenever his bid is lower than the insider's bid, which happens with probability $1 - H_{Gj}^I(D)$. Analogous arguments apply to the case where, with probability $\Pr(\mu_B|\phi_j)$, the outside creditor believes the firm state to be bad.

The inside creditor conditions his bid on the public signal and the actual state. His expected payoff, for a submitted bid of D, state μ_i, and signal ϕ_j, is

$$\begin{aligned}
\Pi_{Gj}^I(D) &= (1 - H_j^O(D))\hat{p}_G(D - D_G), \\
\Pi_{Bj}^I(D) &= (1 - H_j^O(D))\hat{p}_B(D - D_B),
\end{aligned}$$

where $1-H_j^O(D)$ is the probability of submitting the winning bid, given the outside creditor's strategy.

The bidding strategies. Figure 1 shows the bidding strategies of the inside and outside creditors upon good and bad signals (and conditional also on the state for the insider). It is straightforward to see that any equilibrium bidding strategy, for either creditor, has to assign zero probability to bid strictly above $D_B = K/\hat{p}_B$, the break-even debt repayment for a (certain) bad state. Otherwise, the respective other bidder would have an incentive to undercut. In fact, upon observing the bad state, given the conjectured risk choice $\hat{p}_B$, the inside creditor will *always* bid D_B, as shown by the blue mass point in Figure 1a, because any bid below D_B would result in a loss. Only upon observing the good state will the inside creditor bid according to a nontrivial (mixed) strategy, which is the best response to the conjectured bidding behavior on the part of the outside creditor.



(a) Inside creditor

(b) Outside creditor

Figure 1: Insider and outsider's bidding strategies

The outside creditor observes only the public signal ϕ_j and randomizes his bid over the support $[D_j, D_B]$. His bids are bounded from above by D_B (given the arguments above), and from below by D_j, the break-even face value conditional on the public signal ϕ_j, and the conjectured risk choice. Given his information set, submitting a bid below D_j would result in a loss in expectation for the outsider. The inside creditor, having observed the good state, also plays a mixed strategy and randomizes over the same range of face values. In equilibrium, therefore, given a good state, the support for both creditors' bidding strategies is the same, $[D_j, D_B]$, whereas in the bad state the outsider falls victim to the winner's curse. In Figure 1a, the solid and dashed lines describe the insider's mixed strategy in the good state, given good and bad signals, respectively; and the blue mass point describes the insider's bid in the bad state. To alleviate the winner's curse, the outsider bids the upper bound D_B with a mass point $1 - \Phi_j$, and randomizes his bids over the range of $[D_j, D_B)$ with probability Φ_j. In Figure 1b, the solid and dotted lines describe the outsider's mixed strategy given good and bad signals, respectively. By straightforward updating, the mass point D_B is more pronounced given a bad signal.

Substituting D_j, D_B, and D_G yields

$$\Phi_j = H^O_j(D_B) = \frac{\hat{p}_G \Pr(\mu_G|\phi_j)}{\hat{p}_G \Pr(\mu_G|\phi_j) + \hat{p}_B \Pr(\mu_B|\phi_j)}. \tag{10}$$

In line with Rajan (1992), we interpret Φ_j as a measure of the outsider's active participation in the bidding, which is going to play an important role in the analysis below.[13]

The expected payoffs. The outside creditor will incur a loss in the bad firm state whenever he actively participates. This expected loss is just offset by the fact that, in the good state, the outside creditor wins the auction with strictly positive probability and makes a profit because even his lowest bid, in equilibrium, will exceed D_G. Therefore, in expectation over the firm's state and public signal, $E[\Pi_2^O(D)] = 0$.

The inside creditor breaks even for a bad state (as he will always bid D_B), but earns strictly positive expected rents in the good state, following similar arguments just made for his less-informed counterpart. Taking expectations over the state realization, relationship lending allows the inside creditor to earn expected rents from second-period lending:[14]

$$E[\Pi_2^I] = \pi[qD_g(\hat{\mathbf{p}}) + (1-q)D_b(\hat{\mathbf{p}}) - K] > 0. \tag{11}$$

Given competitive credit markets, the borrower extracts this expected second-period information rent ex ante by reducing the period-one face value D_1 accordingly, as per (3).

4.2 The Expected Face Value of Debt

The key determinant of the firm's risk-shifting incentive is the expected second-period face value of debt. Due to the call option feature of debt, the higher is the expected face value, the more risk the firm is willing to take on. Given the optimal bidding strategies, we calculate the expected debt repayments at date 2, $E[D_2|\mu_i, \phi_j, \hat{\mathbf{p}}]$, conditional on the realized

[13]This is with slight abuse of terminology because Rajan (1992) assumes that in case of a tie, the inside creditor always wins, whereas we assume a coin toss as tie-breaking rule. Therefore, even if the outsider bids D_B, there is a nonzero probability he will win the auction—and hence "participate" in the lending in a technical sense. But it is common knowledge that the loan in that case must have zero NPV.

[14]The expression in (11) follows because mixing in equilibrium requires indifference between any bid in the randomization support, and for the lower bound of that support the insider would win the auction almost surely.

state μ_i, the signal ϕ_j, and the conjectured risk choices $\hat{p}_i$,

$$E[D_2 \mid \mu_G, \phi_j, \hat{\mathbf{p}}] = \int_{D_j(\hat{\mathbf{p}})}^{D_B(\hat{p}_B)} [\underbrace{h^I_{Gj}(x)(1 - H^O_j(x))}_{(a)} + \underbrace{h^O_j(x)(1 - H^I_{Gj}(x))}_{(b)}]x \; dx, \quad (12)$$

$$E[D_2 \mid \mu_B, \phi_j, \hat{\mathbf{p}}] = \underbrace{\int_{D_j(\hat{\mathbf{p}})}^{D_B(\hat{p}_B)} h^O_j(x)x \; dx}_{(c)} + \underbrace{(1 - \Phi_j)D_B(\hat{p}_B)}_{(d)}. \quad (13)$$

In the good state μ_G, for any a signal ϕ_j, both creditors mix their respective bids over the support $[D_j, D_B]$, and the expected face value of debt in (12) allows for the possibility that either the insider wins (a) or the outsider wins (b). In the bad state, the insider always bids D_B, whereas the outsider continues to randomize over $[D_j, D_B]$ with probability $1 - \Phi_j$, in which case he will undercharge the borrower, as in (c). If the outsider also effectively "exits" the auction, the loan will be fairly priced at D_B, as in (d).

The expected face values of debt in (12) and (13) yield some immediate observations. First, the expected debt repayment in the good state is always higher than that under perfect information ($q \to 1$): $E[D_2 \mid \mu_G, \phi_j, \hat{\mathbf{p}}] > D_G$. Thus, both creditors expect to earn positive rents in the good state. On the other hand, the expected debt repayment in the bad state is lower than with perfect information: $E[D_2 \mid \mu_B, \phi_j, \hat{\mathbf{p}}] < D_B$. Whenever the face value is below the fair value D_B, the loan is made by the outsider, and the firm benefits from the winner's curse. Second, because both creditors mix over bids between $[D_j, D_B]$, it must be that $E[D_2 \mid \mu_i, \phi_j, \hat{\mathbf{p}}] > D_j$. That is, compared with the break-even face value D_j in the benchmark with symmetrically informed creditors (Proposition 1), the expected face value is higher if some creditors are informed of the state. This is a consequence of the outside creditor price-protecting against the winner's curse and the insider's optimal response.

4.3 Equilibrium Risk Shifting

We now examine the borrower's risk choice in the bad state. After observing a bad state realization, the firm chooses a level of project risk that maximizes its expected payoff, given the creditors' conjectures. The first-order condition of (1) gives[15]

$$R(p,\mu_i) - r - E[D_2|\mu_i,\hat{\mathbf{p}}] = 0. \tag{14}$$

The expected debt repayment $E[D_2|\mu_i,\hat{\mathbf{p}}]$ in (14) is calculated as

$$\begin{aligned} E[D_2|\mu_G,\hat{\mathbf{p}}] &= qE[D_2|\mu_G,\phi_g,\hat{\mathbf{p}}] + (1-q)E[D_2|\mu_G,\phi_b,\hat{\mathbf{p}}], &(15)\\ E[D_2|\mu_B,\hat{\mathbf{p}}] &= qE[D_2|\mu_B,\phi_b,\hat{\mathbf{p}}] + (1-q)E[D_2|\mu_B,\phi_g,\hat{\mathbf{p}}], &(16)\end{aligned}$$

using (12) and (13). In equilibrium, the creditors' conjectures are correct, $\hat{p}_i = p_i$ for any i. If there exists an interior solution, therefore, the equilibrium risk choice p_i^* is characterized by the implicit function

$$R(p_i^*,\mu_i) - r - E[D_2|\mu_i,p_B^*,p_G^*] = 0. \tag{17}$$

Proposition 3 *With asymmetrically informed creditors, in equilibrium:*

(i) The firm chooses the risk-free project in the good state and engages in risk shifting in the bad state: $p_B^* < p_G^* = 1$.

(ii) For any $q < 1$, p_B^* is higher than for $q = 1$, i.e., the firm's risk-shifting behavior is most extreme if the public signal is perfectly informative.

(iii) For $q < 1$, p_B^* is riskier than if the creditors are symmetrically informed: $p_B^* < p_B^n$.

If the public signal were perfect ($q = 1$), all creditors would learn the firm state, and all loans would be fairly priced with certainty—at the fair value D_B in the bad firm state. Noise in the public signal ($q < 1$) introduces information asymmetry among creditors. The resulting expected face value of debt in the bad state, $E[D_2 \mid \mu_B, p_G = 1, p_B]$, thus is strictly less than D_B. Perfect public signals therefore maximize the risk-shifting incentive by pushing the borrower's call option farthest out of the money. Put differently, noise in the signal ϕ_j ensures that the outside bidder in the bad firm state will actively participate in the bidding

[15] It is easy to verify that the second-order condition holds, as $\partial U^2(\cdot)/\partial p$ is proportional to $-r/p < 0$.

and offer a subsidized loan, in expectation. The winner's curse thus comes with a silver lining: it alleviates the borrower's risk shifting incentive. This stands in stark contrast to Rajan's (1992) model without a state-contingent risk choice, in which a perfect public signal maximizes efficiency.

The welfare-increasing role of measurement noise in our setting arises through a qualitatively different mechanism than that in earlier studies such as Kanodia et al. (2005). In their model, introducing noise mitigates a signal jamming problem that would arise if accounting information were to perfectly reveal a firm's investment; i.e., measurement noise helps alleviate overinvestment. In our model, it reduces state-contingent risk-shifting by making the public signal imperfectly informative about the bad state in which borrowers' temptation to engage in asset substitution is most pronounced.

As part (iii) of Proposition 3 shows, the firm's risk shifting in the presence of an informed creditor is always more pronounced than if the creditors were symmetrically informed, $p_B^* < p_B^n$. The insider never participates in the bad firm state. The outside creditor reacts to the specter of the winner's curse by probabilistic nonparticipation and price protection. Together these effects drive up the face value of debt in expectation, as compared with the case where all creditors only ever learn the public signal. As a result, the presence of a privately informed creditor further drives the firm's call option out of the money. In that sense, our model identifies another cost of relationship lending—excessive risk-taking—that is qualitatively different than the hold-up effects in earlier studies such as Rajan (1992).

5 The Effect of Public Information Precision

We now study the effect of information precision on the firm's risk choice in more detail. Proposition 3 may suggest that increasing precision, even locally, always exacerbates the asset substitution problem in bad firm states, because such states are identified more precisely to all potential lenders. As we will show below, this conclusion is not generally valid. We build on Proposition 3, whereby our maintained assumptions imply that $p_G^* = 1$, in equilibrium.

Taking this fact as given, we henceforth omit $\hat{p}_G$ from the notation and focus on the analysis of risk-taking in the bad state only.

5.1 Information Precision and the Bidding Outcome

Having observed a bad firm state, the insider always bids D_B, irrespective of the information precision. Hence, the information precision affects the expected bidding outcome in the bad state only through its effect on the outsider's bidding behavior.

Lemma 2 *Suppose the firm state is bad. As the public information precision q increases, the expected debt repayment upon a good (bad) signal decreases (increases):*

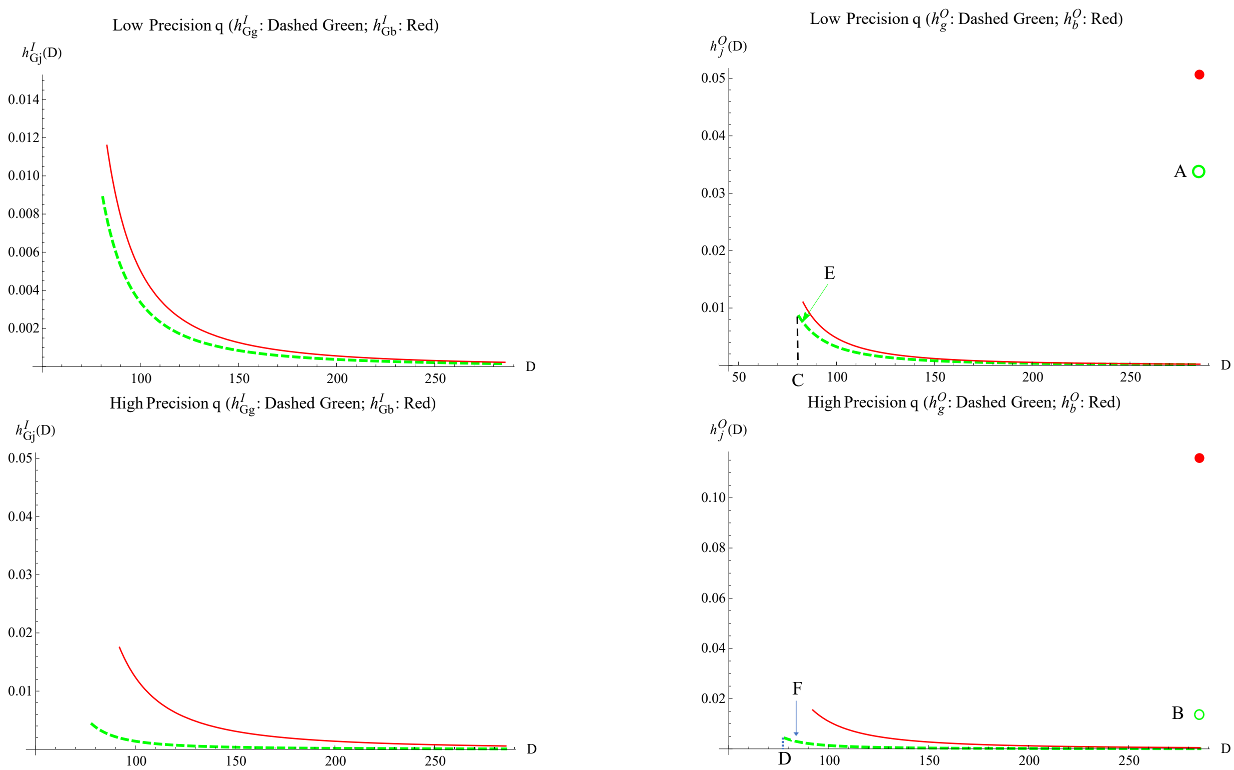
$$\frac{\partial E[D_2|\mu_B, \phi_g, \hat{p}_B]}{\partial q} < 0 < \frac{\partial E[D_2|\mu_B, \phi_b, \hat{p}_B]}{\partial q}.$$

The outsider's bidding behavior is described by his willingness to participate, Φ_j, the minimum bid for the face value, D_j, and the mixing density if he participates, $h_j^O(\cdot)$, all of which are nontrivial functions of q. To study the effect of accounting information precision on the expected debt repayment, we take the derivative of (13) with respect to q:

$$\frac{\partial E[D_2|\mu_B, \phi_j, \hat{p}_B]}{\partial q} = -D_B\frac{\partial \Phi_j}{\partial q} - \frac{\partial D_j(q)}{\partial q}h_j^O(D_j(q)|q)D_j(q) + \int_{D_j(q)}^{D_B} \frac{\partial h_j^O(x|q)}{\partial q}xdx. \quad (18)$$

A more precise public signal alleviates the information asymmetry between creditors. Figure 2 illustrates the changes in the creditors' bidding strategies upon good and bad signals as the information precision changes. We focus on explaining the changes in the outside creditor's strategy, because the insider will always bid D_B in the bad state (and will optimally adapt his strategy to that of the outsider in the good state).

In Figure 2b, the solid and dashed lines describe the outsider's bidding density function, and the solid and circle dots at the upper bound represent the mass points at D_B, upon good and bad signals, respectively. Consider the effect of an increase in signal precision in case of a good signal realization (the dashed line), ϕ_g. The outside creditor then: (i) is more likely to actively participate in the bidding ($\partial \Phi_g/\partial q > 0$), as shown by the mass point of bidding



(a) Inside creditor

(b) Outside creditor

Figure 2: Information precision and bidding strategies

at the upper bound moving from A to B; (ii) mixes his bids over a support that is expanding to the left, if he actively participates ($\partial D_g/\partial q < 0$), as shown by the lower bound of his bidding range moving from C to D; and (iii) mixes his bid with a lower density over this "lower" support, that is, $\partial h_g^O(\cdot)/\partial q < 0$, as shown by the dashed line moving from E to F. In the bad state, the overall net effect of an increase in signal precision is a reduction in the expected period-two debt repayment conditional on a good signal realization. Intuitively, the outside creditor bids more aggressively upon observing a good signal with high precision. The preceding arguments are reversed for a bad signal realization (as represented by the solid line and dot), implying that more precise information then *increases* the expected debt repayment.

5.2 Information Precision and Risk-Shifting

The borrower's risk shifting incentives are determined by the expected face value of debt conditional on a bad state, as per Date 1, i.e., *prior to* the realization of the public signal. To determine how more precise information affects asset substitution, we need to trade off the countervailing effects on debt repayments for the alternative signals described in Lemma 2. Applying the Implicit Function Theorem to the firm's optimal risk choice condition in equation (17) yields

$$\frac{dp_B^*}{dq} = \frac{\frac{\partial E[D_2|\mu_B, p_B^*]}{\partial q}}{\frac{\partial R(p_B,\mu_B)}{\partial p_B^*} - \frac{\partial E[D_2|\mu_B, p_B^*]}{\partial p_B^*}}. \tag{19}$$

The denominator of (19) represents the second-order condition for the optimal risk choice; it is always negative given the maintained assumption that r is sufficiently large. Thus the effect on the risk-shifting incentive in the bad state hinges on the numerator, i.e., on the effect of accounting precision on the expected face value of debt.

The expected debt repayment conditional on the bad state in equilibrium is given by (16) with $\hat{p}_B$ replaced by p_B^*:

$$E[D_2 \mid \mu_B, p_B^*] = qE[D_2 \mid \mu_B, p_B^*, \phi_b] + (1-q)E[D_2 \mid \mu_B, p_B^*, \phi_g]. \tag{20}$$

Therefore:

$$\begin{aligned}\frac{\partial E[D_2 \mid \mu_B, p_B^*]}{\partial q} &= \underbrace{E[D_2 \mid \mu_B, p_B^*, \phi_b] - E[D_2 \mid \mu_B, p_B^*, \phi_g]}_{\text{(i) Direct effect } > 0} \\ &\quad \underbrace{+q\frac{\partial E[D_2 \mid \mu_B, p_B^*, \phi_b]}{\partial q} + (1-q)\frac{\partial E[D_2 \mid \mu_B, p_B^*, \phi_g]}{\partial q}}_{\text{(ii) Indirect effect, sign?}}.\end{aligned} \tag{21}$$

The total effect of a change in information precision on the expected face value can be decomposed into a direct and an indirect effect. Given the bad state μ_B, the direct effect is that greater information precision makes the bad (good) signal more (less) likely. The direct effect is strictly positive because $E[D_2 \mid \mu_B, p_B^*, \phi_b] > E[D_2 \mid \mu_B, p_B^*, \phi_g]$, reflecting that unfavorable signals will drive up the face value of debt. The indirect effect stems from the way a change in q affects the updating and bidding process for given signal realizations. A priori, the indirect effect can take either sign, as greater precision drives up the face value conditional on a bad signal, but reduces it for a good signal, as per Lemma 2.

Our main result is driven by the fact that, under certain conditions, the indirect effect outweighs the direct effect, resulting in the risk shifting incentive being reduced locally by greater information precision. These conditions can be tied rather intuitively to the economic environment in which the firm operates, specifically to the prior about the firm state, π. To set the stage for our main result, we introduce two functions,

$$\underline{\pi}(p_B, q) \equiv \frac{1}{1 + \frac{q(1-\lambda)}{p_B(1-q)\lambda}} \quad \text{and} \quad \bar{\pi}(p_B, q) \equiv \frac{1}{1 + \frac{(1-q)(1-\lambda)}{p_B q \lambda}}, \tag{22}$$

where $\bar{\pi}(p_B, q) > \underline{\pi}(p_B, q)$ for any (p_B, q), and $\lambda \equiv 1 - \exp[-1/2] \approx 0.393$ is an exogenous parameter. Moreover, let p_B^o denote the equilibrium risk choice in the special case of the main model where the public signal is perfect, i.e., $p_B^o \equiv p_B^*(q = 1)$.

Proposition 4 ***[The effect of public information precision on risk shifting]*** *There exists threshold levels for the prior, $\{\underline{\pi}(p_B^o, q), \bar{\pi}(p_B^n, q)\}$, such that:*

(i) if $\pi < \underline{\pi}(p_B^o, q)$, then the firm will take less risk in the bad state for more precise public information, i.e., $dp_B^*/dq > 0$;

(ii) if $\pi > \bar{\pi}(p_B^n, q)$, then the firm will take more risk in the bad state for more precise public information, i.e., $dp_B^*/dq < 0$.

The prior on the firm state determines qualitatively how public information precision affects risk shifting. Intuitively, if the prior belief π is sufficiently small, the outside creditor anticipates a high default risk and asks for a correspondingly high face value of debt. Upon observing a bad signal ϕ_b, the outsider's posterior belief then reacts rather insensitively to a change in signal precision, as the signal merely confirms the prior. Put differently, given a bad signal, the outsider will bid even more conservatively as q increases, but the marginal effect will be small—and hence so will be the change in the insider's optimal response (if the firm is in the good state). On the other hand, the outsider's posterior belief reacts sensitively to an improvement in the signal precision conditional on a good signal realization, ϕ_g, because for small π the signal now runs counter to the prior. That is, given a good signal, the outsider will bid significantly more aggressively as q increases—inducing the insider to bid significantly more aggressively, as well (in the good firm state). As a result, the marginal effect of the information precision on D_g is greater than that on D_b, resulting in a negative indirect effect.

Moreover, while the total direct effect in (21) is always strictly positive, its magnitude is small if the prior π is small. For small π, the outside creditor anticipates a high default risk. As a result, the break-even face values $\{D_g, D_b\}$ tend to be high for any realization of the public signal, but the face value *differential* $(D_b - D_g)$ becomes small—and it is this differential that drives the direct effect. Overall, therefore, for pessimistic priors, more precise public information tends to alleviate risk-shifting incentives. This holds even though bad firm states get revealed more precisely, and it is in those states that asset substitution occurs in our setting.

For optimistic priors about the borrower' state, i.e., π is high, these effects are reversed: the outsider's posterior belief now reacts more (less) sensitively to a change in the signal precision if a bad (good) signal is observed. Hence, the indirect effect is positive in aggregate and thus compounds the direct effect (which will be more pronounced, as the face value differential $(D_b - D_g)$ is increasing in π). Greater signal precision then leads to more risk shifting in bad firm states.[16]

[16]Looking at the indirect effect in isolation, substituting (18) into (21), we get (see Appendix for details):

$$\text{Part (ii) of (21)} \;\equiv\; -q\frac{\partial D_b}{\partial q}\ln(1-\Phi_b) - (1-q)\frac{\partial D_g}{\partial q}\ln(1-\Phi_g),$$

where $\ln(1-\Phi_g) < \ln(1-\Phi_b) < 0$ because $1 > \Phi_g > \Phi_b > 0$. Furthermore, $\partial D_g/\partial q < 0$ while $\partial D_b/\partial q > 0$. For any given p_B, the total indirect effect of (ii) is strictly negative if the prior belief is sufficiently pessimistic, $\pi < \left(1+\frac{q}{(1-q)p_B}\right)^{-1}$, but is strictly positive for $\pi > \left(1+\frac{1-q}{p_B q}\right)^{-1}$. The sufficient conditions stated in Proposition 4 modify these π-thresholds so as to facilitate trading off direct and indirect effects.

Taking accounting as the main source of public information about potential borrowers, our results have implications for the regulation of financial reporting along the business cycle. Improving financial reporting precision tends to reduce firms' incentive to engage in risk-shifting if the firm's ex-ante outlook is pessimistic, and vice versa. During economic boom times, the prior π tends to be high, and expected default rates low. Regulators' effort to tighten financial reporting precision then may induce more risk-shifting behavior among firms financed with debt. In contrast, during economic downturns, when more firms are expected to be in a bad state, regulators' tendency to relax financial reporting stringency may again exacerbate risk-shifting. In other words, pro-cyclical financial reporting regulation (Bertomeu and Magee, 2011) may adversely affect the economy by inducing excessive risk-taking throughout the business cycle.

6 Creditor Turnover

We next examine how the precision of public information affects creditor turnover. Increased precision levels the playing field among creditors, so one might expect it to help new creditors get a foot in the door. However, the prior analysis has shown that the effect of public information on the outcome of the auction for lending is complex, given the strategic interaction between the creditors. Moreover, as we have seen, the signal precision affects the firm's equilibrium risk choice, which is likely also to have an effect on creditor turnover.

While the primitive information asymmetry among the creditors in our setting pertains to the firm's state, the fact that risk taking is state-contingent implies that the insider will be better informed also about the firm risk. Specifically, in equilibrium, the insider knows p_i^* pointwise for each state, whereas the outsider only anticipates the firm risk *on average* across firm states. Information asymmetry with regard to the firm *state* therefore engenders information asymmetry with regard to key firm *actions*—here, a risk choice.

The borrower switches creditors whenever the outside creditor bids a lower face value of debt than the insider, or—with probability 1/2—in case of a tie. The probability of creditor turnover conditional on the state and public signal, in equilibrium, is readily derived from the bidding strategies in Proposition 2. Recall that for a bad firm state, the inside creditor always bids the highest face value of debt, D_B. The outside creditor bids D_B with probability $1-\Phi_j$, resulting in a tie; with probability Φ_j, he randomizes over lower face values and wins the auction (albeit at a loss). Hence the probability of creditor turnover, given a bad state and a signal realization ϕ_j, is

$$\Pr(\text{Turnover} \mid \mu_B, \phi_j) = \frac{1+\Phi_j}{2}. \tag{23}$$

For a good firm state, the outside bidder's strategy remains the same (as he does not learn the state). But now the inside bidder, with probability one, will randomize over the same face value support. Moreover, by Proposition 2, the creditors' respective bidding densities over this face value support are identical up to a scalar, as $h^I_{Gj}(D) \equiv \frac{1}{\Phi_j} h^O_j(D)$ for any $D \in [D_j, D_B)$, $j = g, b$. Hence the probability of creditor turnover, given a good firm state and a signal realization ϕ_j, is

$$\Pr(\text{Turnover} \mid \mu_G, \phi_j) = \int_{D_j}^{D_B} H^O_j(x) h^I_{Gj}(x) dx = \frac{\Phi_j}{2}. \tag{24}$$

Two observations follow immediately. First, regardless of the public signal, firms are less likely to switch creditors in the good state than in the bad state, i.e., $\Pr(\text{Turnover} \mid \mu_G, \phi_j) <$ $\Pr(\text{Turnover} \mid \mu_B, \phi_j)$, for any ϕ_j. This is merely another manifestation of the winner's curse: outside creditors with information disadvantage are more likely to "win lemons." Second, for any firm state μ_i, the firm is more likely to switch creditors upon observing a good signal, i.e., $\Pr(\text{Turnover} \mid \mu_i, \phi_g) > \Pr(\text{Turnover} \mid \mu_i, \phi_b)$ for any μ_i, because the outside creditor bids more aggressively than he would upon observing a bad signal (which is only partially offset, in the good state, by the insider's optimal response). Taking expectations over signal realizations, we obtain the probability of creditor turnover conditional only on the firm state:

$$\Pr(\text{Turnover} \mid \mu_G) = \frac{q\Phi_g + (1-q)\Phi_b}{2}, \qquad \Pr(\text{Turnover} \mid \mu_B) = \frac{1 + (1-q)\Phi_g + q\Phi_b}{2}. \tag{25}$$

It is easy to see that for any given conjectured risk choice, the probability of turnover is lower in the good state, i.e., $\Pr(\text{Turnover} \mid \mu_G) < \Pr(\text{Turnover} \mid \mu_B)$—the winner's curse again.

We now examine the effect of public information precision on the stability of the lending relationship. As a preliminary step, we fix the firm's state and its risk choice:

Lemma 3 *For given conjectured risk choice, $\hat{p}_B$, more precise public information increases the probability of creditor turnover in the good state, and decreases it in the bad state, i.e., $\partial \Pr(\text{Turnover} \mid \mu_G)/\partial q > 0 > \partial \Pr(\text{Turnover} \mid \mu_B)/\partial q$.*

More precise public information decreases the outsider's willingness to participate in the bidding conditional on a bad signal realization ($\partial\Phi_b/\partial q < 0$) and increases it conditional on a good signal realization ($\partial\Phi_g/\partial q > 0$). For a good firm state, therefore, greater precision makes a good public signal more likely, which would induce the outside creditor to bid lower more aggressively. This results in a higher probability of creditor turnover, even taking into account the insider's optimal response. Converse arguments apply for a bad firm state (except the insider will not change his bidding strategy and continue to bid D_B always)—greater signal precision then reduces the probability of turnover.

Our main object of interest, however, is the *ex-ante* probability of creditor turnover, which we denote by

$$\Omega \;\equiv\; \pi \cdot \Pr(\text{Turnover} \mid \mu_G) + (1-\pi) \cdot \Pr(\text{Turnover} \mid \mu_B).$$

The total effect of increasing information precision on Ω can be decomposed as follows:

$$\frac{d\Omega}{dq} = \underbrace{\frac{\partial\Omega}{\partial q}}_{\text{Direct effect}} + \underbrace{\left(\left.\frac{\partial\Omega}{\partial\hat{p}_B}\right|_{\hat{p}_B=p_B^*}\right)\cdot\frac{dp_B^*}{dq}}_{\text{Indirect effect}}. \tag{26}$$

The direct effect captures the impact of q on the probability of creditor turnover, holding fixed the risk choice p_B^*. The indirect effect represents the impact on the risk choice p_B^*, which in turn affects the probability of turnover.

Proposition 5 *With an endogenous risk choice, increasing the precision of public information reduces the probability of creditor turnover for sufficiently pessimistic priors about the firm state; specifically,* $d\Omega/dq < 0$ *if* $\pi < \underline{\pi}(p_B^o, q)$.

Key to this result is that the direct effect in (26) is always negative, i.e., holding fixed the borrower's project choice, greater signal precision reduces the probability of turnover. While we show this formally in the proof, here we provide the economic intuition. Note that the direct effect constitutes a weighted average of the state-by-state comparative statics described in Lemma 3. Because these were of countervailing sign, for the overall direct effect to be negative, an increase in the signal precision must have a stronger effect, in absolute terms, on the creditor turnover probability in the bad state (where it was negative) than in the good state (where it was positive). In the bad state, any change in q only affects the bidding behavior of the outsider, as the insider always bids D_B. In the good state, a change in the signal precision affects the outsider's bidding behavior just as in the bad state, *but now the insider optimally reacts to the anticipated bidding behavior of the outsider.* With bidding strategies in auctions typically being strategic complements, the effect of q on the outsider's bidding behavior (more aggressive upon a good signal ϕ_g; more conservative upon a bad signal ϕ_b) will be partially offset by the insider's best response. No such a strategic interaction is present in the bad state. Hence, the effect of q on the turnover probability in the bad state is the dominant one, making the overall direct effect of q on Ω negative.

To evaluate the indirect effect in (26), for any firm state, it is easy to show that the probability of creditor turnover increases with the conjectured project risk in the bad state, i.e., $\partial\Omega/\partial\hat{p}_B \leq 0$. Hence a sufficient condition for more precise public information to increase the stability of the lending relationship therefore is that it induces a safer project choice, i.e., $dp_B^*/dq \geq 0$. Proposition 4 has identified a sufficient condition for this to be the case, namely a sufficiently pessimistic prior about the firm, as $dp_B^*/dq \geq 0$ for $\pi < \underline{\pi}(p_B^o, q)$.

Our model provides testable empirical implications for how the quality of public information, such as accounting earnings, affects the stability of lending relationships.[17] We predict that for pessimistic priors about the borrower state, increasing information quality tends to increase the duration of lending relationships, despite it levelling the playing field in the credit market. One can think of various empirical proxies for the prior, π, to test this hypothesis. For example, Bushman et al. (2017) suggests media sentiment as a measure of expectations about the borrower's credit fundamentals. Our model then suggests that when market sentiment is low, higher public information quality decreases the likelihood of creditor turnover.[18] One may also test our model's prediction using the propensity of creditor turnover along the business cycle: during economic downturns, lending relationship should become more stable when regulators improve financial reporting quality. A caveat to these predictions is that information quality tends to be endogenous, as well. Hence, to test our predictions empirically, it would be helpful if one could identify an exogenous shock to information quality that is not tied to characteristics of an industry, of lending activities, or of the business cycle.[19]

[17]There are not many empirical studies that have directly examined these related questions. Ioannidou and Ongena (2010) study the characteristics of switching loans, and find that firms switch to outside creditors tend to receive a lower loan spread, and these creditors gradually increase the loan spread over time, consistent with the existence of asymmetric information between new and existing creditors and hold-up problem by incumbent creditors.

[18]Bushman, et. al. (2017) examine the role of media sentiment on the origination of syndicated loans (not switching) when there are both relationship and non-relationship creditors. Their find that when the media sentiment is high, non-relationship creditors have a higher probability of originating loans (switching) and are more likely to participate in syndicated loans. However, Bushman et al. (2017) do not test whether financial information quality has a differential marginal impact on turnover, conditional on market sentiment. If one interprets firms' past credit history as a probabilistic expected creditworthiness of the borrower, i.e., of the prior in our model, then recent results in Sutherland (2018) are related as well. After creditors adopt PayNet to share information about their borrowers, Sutherland (2018) finds a positive and significant reaction on creditor turnover for firms with strong credit history, and a negative but insignificant reaction on turnover for firms with weak credit history.

[19]Sutherland (2018) and Doblas-Madrid and Minetti (2013) use lenders joining PayNet (a web-based bureau) to identify an exogenous shock to the change of information environment to creditors. However, information shared by informed lenders may also be strategic and endogenously determined, different from our model's setting. To carry out empirical tests of our model, one may look for settings where the exogenous shock to borrowers' public information is not driven by creditors' activities.

7 Conclusion

In this paper, we analyze the role of public (accounting) information precision in debt financing when creditors are asymmetrically informed. We show that changes in accounting precision can have qualitatively different effects on the severity of the asset substitution problem and on the stability of lending relationships, depending on the prior regarding the firm's economic health. The predictions are closely related in that the sufficient conditions that predict greater accounting precision to alleviate risk shifting—namely, a pessimistic prior—are also sufficient for predicting more stable lending relationships (i.e., a reduction in the probability of creditor turnover). These results can easily be tied in with conditions describing the business cycle or other observable firm- or industry-level characteristics and hence lend themselves to empirical testing.

Our model highlights the importance of endogeneity issues in relationship lending settings. Information asymmetry regarding the (exogenous) creditworthiness (or "state") of a firm on the part of an incumbent creditor may engender information asymmetry also with regard to other, endogenous, variables, such as firm risk. This theme of "proliferation" of information asymmetry is likely to be applicable to other financial contracting settings, as well.

Appendix: Proofs

Proof of Proposition 1

The proof proceeds with two steps. First, we identify the conditions under which with symmetrically informed creditors, the firm's project choice in the good state is risk free ($p_G^n = p_G^{fb} = 1$). Define that $\underline{\mu}_G \equiv D_B(p_B^o)$, where $D_B(p_B^o)$ is the debt face value when the states are perfectly known, and p_B^o is the equilibrium risk choice in the bad state with perfect information ($q = 1$). With symmetrically informed creditors but non-contractible risk choice, the equilibrium risk choice $p_i^n \in (0, 1)$, if it is an interior solution, is characterized by the first order conditon:

$$R(p_i^n, \mu_i) - r - E[D_2^n \mid \mu_i, \hat{\mathbf{p}}^n] = 0, \tag{27}$$

where $\hat{\mathbf{p}}^n = (\hat{p}_G^n, \hat{p}_B^n)$, $E[D_2^n \mid \mu_G, \hat{\mathbf{p}}^n] = qD_g(\hat{\mathbf{p}}^n) + (1-q)D_b(\hat{\mathbf{p}}^n)$, and $E[D_2^n \mid \mu_B, \hat{\mathbf{p}}^n] = qD_b(\hat{\mathbf{p}}^n) + (1-q)D_g(\hat{\mathbf{p}}^n)$. The second order condition is satisfied:

$$\frac{\partial}{\partial p}\left\{R(p, \mu_G) - r - E[D_2^n|\mu_i, \hat{\mathbf{p}}^n]\right\} = -r/p < 0.$$

Under Assumption 1 that $\mu_B < K < r$ and $\mu_G \geq r + \underline{\mu}_G$, it follows that the first order conditions satisfy

$$R(p_i^n, \mu_i) - r - E[D_2^n \mid \mu_i, \hat{\mathbf{p}}^n]|_{p_i^n=1} = \mu_i - r - E[D_2^n \mid \mu_i, \hat{\mathbf{p}}^n] \begin{cases} > 0, & \text{if } i = G, \\ < 0, & \text{if } i = B. \end{cases}$$

As the first order condition is positive when the state is good, the equilibrium must entail the corner solution $p_G^n = p_G^{fb} = 1$.Second, we show that the project choice in the bad state is riskier than the rst-best level ($p_B^n < p_B^{fb}$). The first-best risk choice p_B^{fb} satisfies

$$R(p_i^{fb}, \mu_B) - r = 0. \tag{28}$$

For any $p_B^n \in (0, 1)$, we have $R(p_B^{fb}, \mu_B) < R(p_B^n, \mu_B)$ by comparing (27) given $i = B$ and (28). Given that $\partial R(p, \mu_i)/\partial p = -r/p < 0$, it follows that $p_B^{fb} > p_B^n$. Note that under some parameter range, there may exist two solutions satisfying (27). In that case, we assume the players coordinate on the Pareto-dominant equilibrium, which entails the lowest risk (i.e., the highest p_i), so as to alleviate the risk-shifting incentive. That is, if the creditor conjectures a higher p_i^n, the firm in equilibrium also chooses a higher low p_i^n to sustain the creditor's belief. With that conjecture, the creditor expects to break even in the equilibrium.

Proof of Proposition 2

Before submitting their bids, the outside (uninformed) creditor observes the public signal ϕ_j, and the inside (informed) creditor observes both the public signal ϕ_j and the state μ_i. Both the inside and outside creditors conjecture the firm's risk choice $\hat{p}_i$ for state μ_i. In this proof, we suppress the p-conjectures as arguments of D_j, D_B and ϕ_j, to avoid clutter. Following the argument in Engelbrecht-Wiggans, Milgrom, and Weber (1983) and Rajan (1992), we show that (1) the equilibrium bids have identical support and (2) no pure strategies exist for the outside creditor.

We first argue that the bidding range is $[D_j, D_B]$, where $D_j = K/[\Pr(\mu_G|\phi_j)\hat{p}_G + (1 - \Pr(\mu_G|\phi_j))\hat{p}_B]$. Here, D_B is the break-even debt repayment given the perfect information about the firm state μ_B. If the inside creditor observes the bad state perfectly, he will not bid any value below the D_B. Hence the upper bound of the bidding range is at least D_B. It also follows that if any creditor bids strictly above D_B with a positive probability, the other creditor can always bid slightly lower and win the bid with a positive profit. Competition between bidders drive down the face value of debt, resulting in D_B as the upper bound. At the same time, D_j is the break-even debt repayment given the public signal ϕ_j. The outside creditor will not submit any bid less than D_j, as doing so would yield a negative expected payoff. The inside creditor will not bid less than D_j either, because this strategy decreases the insider's payoff without increasing the probability of winning. Thus D_j is the lower bound for all bidding strategies.

Second, any pure strategy would make the outside creditor suffer a loss in equilibrium (the winner's curse). Suppose that the outside creditor bids a price $D' \in (D_j, D_B]$, deterministically. The inside creditor would respond by bidding slightly below D' in the good state and D_B in the bad state. The outside-creditor thus wins only in the bad state, in which case he suffers a loss of $D' - D_B$. Consequently, the outside creditor adopts a mixed strategy that randomizes his bids over the bidding range $[D_j, D_B]$. The inside creditor, if the state is bad, adopts a pure strategy, bidding D_B all the time regardless of the public signal. But for a good state, the inside creditor will also randomize his bids over the bidding range, $[D_j, D_B]$.

As shown in Engelbrecht-Wiggans, Milgrom, and Weber (1983), in equilibrium, the outside creditor makes zero profit. Thus we can solve the equilibrium bidding strategy of the inside creditor by setting the outside creditor's expected profit to zero for any bid over the bidding range. To solve for the equilibrium bidding strategy of the outside creditor, apply the argument that the inside creditor is indifferent for any bid (makes a constant profit) over the common bidding range when playing a mixed strategy.

Let $H_j^O(D)$ denote the c.d.f. of the equilibrium mixed bidding strategy of the outside creditor given the public signal ϕ_j, and let $H_{Gj}^I(D)$ and $H_{Bj}^I(D)$ denote the c.d.f. of the equilibrium mixed bidding strategy of the inside creditor given the public signal ϕ_j, and the state μ_G and μ_B respectively. We then obtain the expected payoff of each creditor for any bid $D \in [D_j, D_B]$, given the mixed strategy of the other creditor. Specifically, the expected payoff of the outside creditor is

$$\Pi_j^O(D) = \Pr(G|\phi_j)(1-H_{Gj}^I(D))\hat{p}_G(D-D_G)+(1-\Pr(G|\phi_j))(1-H_{Bj}^I(D))\hat{p}_B(D-D_B), \quad (29)$$

where $D_G = K/\hat{p}_G$ and $D_B = K/\hat{p}_B$. In (29), $1-H_{Gj}^I(D)$ and $1-H_{Bj}^I(D)$ are the probabilities of the outside creditor winning the bid (i.e., the inside creditor bids a higher face value than D), given the true state μ_G and μ_B, respectively.

For the inside creditor, the expected payoff for any randomized bid $D \in [D_j, D_B]$ in the good state is

$$\Pi_{Gj}^I(D) = (1 - H_j^O(D))\hat{p}_G(D - D_G). \quad (30)$$

For a bad state, as argued above, the inside creditor always bids D_B, i.e., $H_{Bj}^I(D) = 0$ for $D \in [D_j, D_B)$, and thus breaks even.

The mixed strategies played by the outside creditor must keep him indifferent, i.e., $\Pi^I_{Gj}(D)$ in (30) must be a constant., for any bid D played with strictly positive probability To find this constant value, we evaluate the inside creditor's payoff at $D = D_j$, which implies $H^O_j(D_j) = 0$, and obtain that $\Pi^I_{Gj}(D_j) = (D_j - D_G)$. Thus for any bid D, the expected payoff must be the same as $\Pi^I_{Gj}(D_j)$. Therefore we have

$$\begin{aligned} & \Pi^I_{Gj}(D) = (1 - H^O_j(D))\hat{p}_G(D - D_G) = \hat{p}_G(D_j - D_G) \\ \Rightarrow \quad & H^O_j(D) = \frac{D - D_j}{D - D_G}. \end{aligned}$$

Similarly, by setting the outside creditor's expected payoff in (29) to zero and substituting $H^I_{Bj}(D) = 0$, we obtain the equilibrium $H^I_{Gj}(D)$,

$$\begin{aligned} H^{Gj}_I(D) &= \frac{\hat{p}_G \Pr(G|\phi_j)(D - D_G) + \hat{p}_B(1 - \Pr(G|\phi_j))(D - D_B)}{\hat{p}_G \Pr(G|\phi_j)(D - D_G)}, \\ &= \frac{D - D_j}{\Phi_j(D - D_G)} = \frac{1}{\Phi_j} H^O_j(D), \end{aligned}$$

where, for a given public signal $\phi_{,j}$

$$\Phi_j \equiv \frac{\hat{p}_G \Pr(\mu_G|\phi_j)}{\hat{p}_G \Pr(\mu_G|\phi_j) + \hat{p}_B(1 - \Pr(\mu_G|\phi_j))} = \frac{D_B - D_j}{D_B - D_G}$$

represents the outside creditor's posterior belief about the probability of non-default in the good state, conditional on the overall likelihood of non-default.

The probability density functions (p.d.f.) of the bidding strategies over the range $[D_j, D_B]$ are given by

$$h^I_{Gj}(D) = \frac{D_j - D_G}{\Phi_j(D - D_G)^2}, \qquad h^O_j(D) = \frac{D_j - D_G}{(D - D_G)^2}.$$

Given that $D_j = \Phi_j D_G + (1 - \Phi_j)D_B$, one can easily check that the c.d.f of the inside creditor's bidding strategy in the good state at $D = D_B$ equals to 1, i.e.,

$$H^I_{Gj}(D_B) = \frac{D_B - D_j}{\Phi_j(D_B - D_G)} = 1.$$

But the c.d.f. of the uninformed outside creditor's bidding strategy at $D = D_B$ is

$$H^O_j(D_B) = \frac{D_B - D_j}{D_B - D_G} = \Phi_j.$$

Proof of Proposition 3

(1) First, we show that, with asymmetrically informed creditors, the risk choice in the good state is a corner solution such that $p_G^* = 1$. Any interior solution for the risk choice given state μ_i, would need to satisfy the first-order condition

$$R(p_i^*, \mu_i) - r - E[D_2|\mu_i, p_G^*, p_B^*] = 0. \tag{31}$$

In case of multiple solutions to (31), we again adopt the convention that the players will coordinate on the Pareto-dominant one that features the highest p_i^*. First, by revealed preference, $\mu_B < \mu_G$ implies that $p_B^* \leq p_G^*$. In the bad firm state, if $p_B^* = 1$, then $p_G^* = 1$ must also hold. Yet, at the boundary, $p_B^* = 1$, in state μ_B, we have

$$R(p_B^*, \mu_B) - r - E[D_2|\mu_B, p_G^* = 1, p_B^* = 1] = \mu_B - r - K < 0, \tag{32}$$

because $\mu_B < r$, by Assumption 1. Therefore, the firm's risk choice in the bad state must be interior, $0 < p_B^* < 1$.

Second, let p_B^o denote the equilibrium risk choice in the special case of the main model where the public signal is perfect, i.e., $p_B^o \equiv p_B^*(q = 1)$. We show that $p_B^o < p_B^* < p_B^{fb}$. The second inequality again follows directly by revealed preference. For the first inequality, recall the derivatives with respect to p_B of the firm's expected payoff conditions in the bad state under the respective information settings:

$$R(p_B, \mu_B) - r - E[D_2|\mu_B, \hat{\mathbf{p}}]|_{\hat{p}_G = p_G^*, \hat{p}_B = p_B^*}\,, \tag{33}$$

$$R(p_B, \mu_B) - r - D_B(\hat{p}_B)|_{\hat{p}_B = p_B^o}\,. \tag{34}$$

Using the fact that $p_G^* > p_B^*$ and $E[D_2|\mu_B, \hat{\mathbf{p}}]$ is strictly decreasing in both conjectures $\hat{p}_i$, $i = G, B$, shows that, for any p_B,

$$\begin{aligned} (33) \quad &> \quad R(p_B, \mu_B) - r - E[D_2|\mu_B, \hat{p}_G, \hat{p}_B]|_{\hat{p}_G = p_B^*, \hat{p}_B = p_B^*} \\ &= \quad R(p_B, \mu_B) - r - D_B(\hat{p}_B)|_{\hat{p}_B = p_B^*}\,, \end{aligned}$$

where the last expression recaptures (34), expect for the risk conjecture. By revealed preference, thus, $p_B^* > p_B^o$.

Proof of Lemma 2

Given the bidding strategies in Proposition 2, the expected debt repayment in the bad state upon a signal ϕ_j, i.e. as stated in (13), is

$$E[D_2|\mu_B, \phi_j, \hat{\mathbf{p}}] = (1-\Phi_j)D_B + \int_{D_j}^{D_B} x h_j^O(x)dx.$$

Taking the first-order partial derivative with respect to q, we have

$$\frac{\partial E[D_2|\mu_B, \phi_j, \hat{\mathbf{p}}]}{\partial q} = -\frac{\partial \Phi_j}{\partial q} D_B - h_j^O(D_j) D_j \frac{\partial D_j}{\partial q} + \int_{D_j}^{D_B} x \frac{\partial}{\partial q} h_j^O(x)dx, \tag{35}$$

where the first term represents the effect on the probability that the outsider will bid the upper bound D_B, the second term is the effect on the outsider's bidding range and the third term is the effect on the probability density function of the outsider's bidding strategy.

Given that $D_j = \Phi_j D_G + (1-\Phi_j)D_B$, we have

$$\frac{\partial \Phi_j}{\partial q} = \frac{\partial D_j}{\partial q} \frac{D_G}{D_G - D_B}. \tag{36}$$

From Proposition 2, $h_j^O(D) = \frac{D_j - D_G}{(D-D_G)^2}$, hence we have $h_j^O(D_j) = 1/(D_j - D_G)$ and $\frac{\partial h_j^O(x)}{\partial q} = \frac{\partial D_j}{\partial q} \frac{1}{(x-D_G)^2}$, from which we obtain that

$$h_j^O(D_j) D_j \frac{\partial D_j}{\partial q} = \frac{\partial D_j}{\partial q} \frac{D_j}{D_j - D_G}, \tag{37}$$

and

$$\begin{aligned}\int_{D_j}^{D_B} x \frac{\partial}{\partial q} h_j^O(x)dx &= \frac{\partial D_j}{\partial q} \int_{D_j}^{D_B} \frac{x}{(x-D_G)^2} dx \\ &= \frac{\partial D_j}{\partial q} \left(\ln(D_B - D_G) - \ln(D_j - D_G) + \frac{D_j}{D_j - D_G} - \frac{D_B}{D_B - D_G} \right)\end{aligned} \tag{38}$$

Substituting (36)–(38) into (35), we have

$$\begin{aligned}
\frac{\partial E[D_2|\mu_B,\phi_j,\hat{\mathbf{p}}]}{\partial q} &= \frac{\partial D_j}{\partial q}\left[\begin{array}{c} \left(\frac{D_B}{D_B-D_G}-\frac{D_j}{D_j-D_G}\right)+\ln(D_B-D_G) \\ -\ln(D_j-D_G)+\left(\frac{D_j}{D_j-D_G}-\frac{D_B}{D_B-D_G}\right) \end{array}\right] \\
&= \frac{\partial D_j}{\partial q}[\ln(D_B-D_G)-\ln(D_j-D_G)] \\
&= \frac{\partial D_j}{\partial q}\ln(\frac{D_B-D_G}{D_j-D_G}) \\
&= -\frac{\partial D_j}{\partial q}\ln(1-\Phi_j) \quad (\text{because } \Phi_j=\frac{D_B-D_j}{D_B-D_G}). \qquad (39)
\end{aligned}$$

Note that

$$\begin{aligned}
\frac{\partial D_j}{\partial q} &= -(D_B-D_G)\frac{\partial \Phi_j}{\partial q}, \quad \text{where:} \qquad (40) \\
\frac{\partial \Phi_g}{\partial q} &= \frac{\Phi_g(1-\Phi_g)}{q(1-q)} \;>\; 0, \\
\frac{\partial \Phi_b}{\partial q} &= -\frac{\Phi_b(1-\Phi_b)}{q(1-q)} \;<\; 0.
\end{aligned}$$

Substituting (40) into (39), and using the fact that $\ln(1-\Phi_j)<0$ for $0<\Phi_j<1$, we obtain that

$$\frac{\partial E[D_2|\mu_B,\phi_g,\hat{\mathbf{p}}]}{\partial q} \;<\; 0 \;<\; \frac{\partial E[D_2|\mu_B,\phi_b,\hat{\mathbf{p}}]}{\partial q}.$$

Proof of Proposition 4

In the proof below, we simplify the notation by omitting the argument p_G^* from all functions and variables, because in equilibrium $p_G^*=1$, irrespective of the accounting precision.

Step 1: Calculate dp_B^*/dq.

From (19), we have

$$\frac{dp_B^*}{dq}=\frac{\frac{\partial E[D_2|\mu_B,p_B^*]}{\partial q}}{\frac{\partial R(\mu_B,p_B^*)}{\partial p_B^*}-\frac{\partial E[D_2|\mu_B,p_B^*]}{\partial p_B^*}}.$$

It is easy to show that as long as r is sufficiently large, the denominator of the above equation is always negative, $\frac{\partial R(p_B^*,\mu_B)}{\partial p_B^*}-\frac{\partial E[D_2|\mu_B,p_B^*]}{\partial p_B^*}<0$. Thus we focus on analyzing the effect of q on the expected debt repayment in the numerator, $\frac{\partial E[D_2|\mu_B,p_B^*]}{\partial q}$.

Step 2: Calculate $\frac{\partial E[D_2|\mu_B,p_B^*]}{\partial q}$.

Recall that $E[D_2|\mu_B,p_B^*]=qE[D_2|\mu_B,p_B^*,\phi_b]+(1-q)E[D_2|\mu_B,p_B^*,\phi_g]$. It follows that

$$\begin{aligned}\frac{\partial E[D_2|\mu_B,p_B^*]}{\partial q} &= \underbrace{E[D_2|\mu_B,p_B^*,\phi_b]-E[D_2|\mu_B,p_B^*,\phi_g]}_{\text{direct effect}} \\ &\quad \underbrace{+q\frac{\partial E[D_2|\mu_B,p_B^*,\phi_b]}{\partial q}+(1-q)\frac{\partial E[D_2|\mu_B,p_B^*,\phi_g]}{\partial q}}_{\text{indirect effect}}, \qquad (41)\end{aligned}$$

In equilibrium, we have

$$\begin{aligned}E[D_2|\mu_B,\phi_j,p_B^*] &= (1-\Phi_j)D_B+\int_{D_j}^{D_B} xh_j^O(x)dx \\ &= D_j-(D_j-D_G)\ln(1-\Phi_j) \qquad (42)\end{aligned}$$

Substituting (42) into (41), the direct effect can be shown to be strictly positive:

$$\begin{aligned}&E[D_2|\mu_B,\phi_b,p_B^*]-E[D_2|\mu_B,\phi_g,p_B^*] \\ =\ &(D_B-D_G)[(\Phi_g-\Phi_b)-(1-\Phi_b)\ln(1-\Phi_b)+(1-\Phi_g)\ln(1-\Phi_g)]>0.\end{aligned}$$

Next, substituting (39) from the proof of Lemma 2 into the indirect effect in (41), we have

$$q\frac{\partial E[D_2|\mu_B,p_B^*,\phi_b]}{\partial q}+(1-q)\frac{\partial E[D_2|\mu_B,p_B^*,\phi_g]}{\partial q}=-q\frac{\partial D_b}{\partial q}\ln(1-\Phi_b)-(1-q)\frac{\partial D_g}{\partial q}\ln(1-\Phi_g).$$

Combining the direct and indirect effects above, we obtain that

$$\begin{aligned}\frac{\partial E[D_2|\mu_B,p_B^*]}{\partial q} &= (D_B-D_G)\left\{\begin{array}{c}[(\Phi_g-\Phi_b)-(1-\Phi_b)\ln(1-\Phi_b)+(1-\Phi_g)\ln(1-\Phi_g)] \\ +\frac{\Phi_g}{q}(1-\Phi_g)\ln(1-\Phi_g)-\frac{\Phi_b}{1-q}(1-\Phi_b)\ln(1-\Phi_b)\end{array}\right\}, \\ &= (D_B-D_G)\left\{\begin{array}{c}(1-\Phi_b)\left[1-\frac{\Phi_b+1-q}{1-q}\ln(1-\Phi_b)\right] \\ -(1-\Phi_g)\left[1-\frac{\Phi_g+q}{q}\ln(1-\Phi_g)\right]\end{array}\right\}. \qquad (43)\end{aligned}$$

Step 3: Determine the sign of $\frac{dE[D_2|\mu_B,p_B^*]}{dq}$.

To sign (43), we introduce a new function

$$f(x)\equiv(1-\Psi(p_B^*,\pi,x))\left[1-\frac{\Psi(p_B^*,\pi,x)+x}{x}\ln(1-\Psi(p_B^*,\pi,x))\right],$$

where $x \in [\frac{1}{2}, 1]$ and

$$\Psi(p_B^*, \pi, x) \equiv \frac{\pi x}{\pi x + (1-\pi) p_B^* (1-x)}. \tag{44}$$

Note that $\Phi_g = \Psi(p_B^*, \pi, q)$ and $\Phi_b = \Psi(p_B^*, \pi, 1-q)$. Therefore, we can rewrite $dE[D_2|\mu_B, p_B^*]/dq$ as a function of $f(q)$ and $f(1-q)$,

$$\frac{dE[D_2|\mu_B, p_B^*]}{dq} = (D_B - D_G)[f(1-q) - f(q)].$$

It follows that

$$f'(x) = \underbrace{\frac{(\Psi(\cdot))^2 (1-\Psi(\cdot))}{x(1-x)^2}}_{>0} \underbrace{[1 + 2\ln(1-\Psi(\cdot))]}_{\equiv \alpha(p_B^*, \pi, x).}.$$

Because $\Phi_g > \Phi_b$, a sufficient condition for $\partial E[D_2|\mu_B, p_B^*]/\partial q < 0$ is that $f'(x) > 0$ or, equivalently, $\alpha(p_B^*, \pi, x) \equiv 1 + 2\ln(1-\Psi(\cdot)) > 0$ for any $x \in [\frac{1}{2}, 1]$. Now, $\alpha(p_B^*, \pi, x) > 0$ if and only if $\Psi(p_B^*, \pi, x) < 1 - \exp(-\frac{1}{2}) \equiv \lambda$. Recall that p_B^o is the equilibrium risk choice in the special case of the main model where the public signal is perfect, i.e., $p_B^o \equiv p_B^*(q = 1)$. Proposition 3 shows that $p_B^* \in (p_B^o, p_B^n)$ where p_B^n is the risk choice if both creditors were symmetrically informed. As $\Psi(\cdot)$ is decreasing in p_B, it follows that $\Psi(p_B^n) < \Psi(p_B^*) < \Psi(p_B^o)$. To ensure that $\partial E[D_2|\mu_B, p_B^*]/\partial q < 0$, a sufficient condition is $\lambda > \Psi(p_B^o, \pi, x = q) > \Psi(p_B^*, \pi, x = q)$ in (44). Solving this inequality yields an upper bound on π, in that $\pi < \underline{\pi}(p_B^o, x = q)$ where the function $\underline{\pi}(\cdot)$ is as defined in (22). Solving this inequality yields an upper bound on π, in that $\pi < \underline{\pi}(p_B^o, x = q)$ where the function $\underline{\pi}(\cdot)$ is as defined in (22). Conversely, a sufficient condition for $\partial E[D_2|\mu_B, p_B^*]/\partial q > 0$ is that $\alpha(p_B^*, \pi, x) < 0$ or $\Psi(p_B^*, \pi, x) > 1 - \exp(-\frac{1}{2}) \equiv \lambda$ for any $x \in [\frac{1}{2}, 1]$. A sufficient condition is $\lambda < \Psi(p_B^n, \pi, x = q) < \Psi(p_B^*, \pi, x = q)$. Solving this inequality gives $\pi > \overline{\pi}(p_B^n, x = q)$, where the function $\overline{\pi}(\cdot)$ is again defined in (22).

Proof of Lemma 3

(a) The probability of turnover to the outside creditor depends on the firm project $\mu_i \in \{\mu_G, \mu_B\}$ and the public signal $\phi_j \in \{\phi_g, \phi_b\}$. When the firm state is μ_G, the probability of turnover for an public signal ϕ_j is given by

$$\begin{aligned}
\Pr(\text{Turnover}|\mu_G, \phi_j) &= \int_{D_j}^{D_B} H_j^O(x) h_{Gj}^I(x) dx \\
&= \int_{D_j}^{D_B} \frac{x - D_j}{x - D_G} \frac{D_j - D_G}{\Phi_j (x - D_G)^2} dx \\
&= \frac{D_j - D_G}{\Phi_j} \left[\frac{1}{2(D_j - D_G)} + \frac{D_j - D_B + D_G - D_B}{2(D_B - D_G)^2} \right] \\
&= \frac{(D_B - D_g)^2}{2(D_B - D_G)^2 \Phi_j} = \frac{\Phi_j}{2}.
\end{aligned}$$

In contrast, when the firm state is μ_B, the informed creditor always bids the highest debt repayment D_B. The outside creditor bids D_B with a positive probability $1 - \Phi_j$, in which case the turnover occurs with a probability of $\frac{1}{2}(1 - \Phi_j)$ given the 50-50 tie-breaking rule. The outsider also randomizes his bids below D_B with a total probability of Φ_j, in which case the switch always occurs. Hence the probability of turnover given the bad state and a signal ϕ_j is $\Pr(\text{Turnover}|\mu_B, \phi_j) = \frac{1}{2}(1 + \Phi_j)$. Thus, the ex-ante probabilities of turnover are

$$\Pr(\text{Turnover}|\mu_G) = \frac{q\Phi_g + (1-q)\Phi_b}{2} \; < \; \Pr(\text{Turnover}|\mu_B) = \frac{1 + (1-q)\Phi_g + q\Phi_b}{2},$$

where the inequality follows from $1 > \Phi_g > \Phi_b > 0$ and $q \geq 1/2$.

(b) We next examine the effect of accounting precision q on the statewise probabilities of creditor turnover, $\Pr(\text{Turnover}|\mu_i)$. Taking the derivative with respective to q yields

$$\frac{\partial \Pr(\text{Turnover}|\mu_G)}{\partial q} = \frac{1}{2} \left(\Phi_g - \Phi_b + q \frac{\partial \Phi_g}{\partial q} + (1-q) \frac{\partial \Phi_b}{\partial q} \right),$$

where

$$\begin{aligned}
\frac{\partial \Phi_g}{\partial q} &= \frac{\pi(1-\pi)p_B}{[q\pi + (1-q)(1-\pi)p_B]^2} = \frac{\Phi_g(1-\Phi_g)}{q(1-q)}, \\
\frac{\partial \Phi_b}{\partial q} &= -\frac{\pi(1-\pi)p_B}{[(1-q)\pi + q(1-\pi)p_B]^2} = -\frac{\Phi_b(1-\Phi_b)}{q(1-q)}.
\end{aligned}$$

Substituting gives

$$\frac{\partial \Pr(\text{Turnover}|\mu_G)}{\partial q} = \frac{1}{2} \left(\Phi_g - \Phi_b + \frac{\Phi_g(1-\Phi_g)}{1-q} - \frac{\Phi_b(1-\Phi_b)}{q} \right).$$

Straightforward algebra yields $\partial \Pr(\text{Turnover}|\mu_G)/\partial q > 0$. Analogous steps for the bad state show that

$$\begin{aligned}
\frac{\partial \Pr(\text{Turnover}|\mu_B)}{\partial q} &= \frac{1}{2}\left(-(\Phi_g - \Phi_b) + (1-q)\frac{\partial \Phi_g}{\partial q} + q\frac{\partial \Phi_b}{\partial q}\right), \\
&= \frac{1}{2}\left(-\Phi_g + \Phi_b + \frac{\Phi_g(1-\Phi_g)}{q} - \frac{\Phi_b(1-\Phi_b)}{1-q}\right) < 0.
\end{aligned}$$

Proof of Proposition 5

We now examine the effect of the accounting information precision on the ex-ante probability of creditor turnover

$$\Omega \equiv \pi \Pr(\text{Turnover}|\mu_G) + (1-\pi)\Pr(\text{Turnover}|\mu_B).$$

The total effect of increasing information precision on Ω is

$$\frac{d\Omega}{dq} = \underbrace{\frac{\partial \Omega}{\partial q}}_{\text{Direct effect}} + \underbrace{\left(\left.\frac{\partial \Omega}{\partial \hat{p}_B}\right|_{\hat{p}_B = p_B^*}\right) \cdot \frac{dp_B^*}{dq}}_{\text{Indirect effect}}.$$

where the risk choice p_B^* is characterized in (19). We first show the direct effect is negative

$$\begin{aligned}
\frac{\partial \Omega}{\partial q} &= \pi\frac{\partial \Pr(\text{Turnover}|\mu_G)}{\partial q} + (1-\pi)\frac{\partial \Pr(\text{Turnover}|\mu_B)}{\partial q}, \\
&= \frac{\pi}{2}\left(\frac{(1-q)\Phi_g + \Phi_g(1-\Phi_g)}{1-q} - \frac{q\Phi_b + \Phi_b(1-\Phi_b)}{q}\right) \\
&\quad - \frac{1-\pi}{2}\left(\frac{q\Phi_g - \Phi_g(1-\Phi_g)}{q} - \frac{(1-q)\Phi_b - \Phi_b(1-\Phi_b)}{1-q}\right) \\
&= \frac{1}{2q(1-q)}\left\{\begin{array}{c} \Phi_g\left[(1-q)^2 - (1-q-\pi)\Phi_g - \pi\right] \\ -\Phi_b[q^2 - (q-\pi)\Phi_b - \pi] \end{array}\right\} < 0.
\end{aligned}$$

The indirect effect $\partial\Omega/\partial p_B^*$ is characterized by

$$\begin{aligned}
\left.\frac{\partial \Omega}{\partial \hat{p}_B}\right|_{\hat{p}_B = p_B^*} &= \pi\frac{\partial \Pr(\text{Turnover}|\mu_G)}{\partial p_B^*} + (1-\pi)\frac{\partial \Pr(\text{Turnover}|\mu_B)}{\partial p_B^*} \\
&= \frac{\pi}{2}\left[q\frac{\partial \Phi_g}{\partial p_B^*} + (1-q)\frac{\partial \Phi_b}{\partial p_B^*}\right] + \frac{1-\pi}{2}\left[(1-q)\frac{\partial \Phi_g}{\partial p_B^*} + q\frac{\partial \Phi_b}{\partial p_B^*}\right],
\end{aligned}$$

where we can show

$$\begin{aligned}
\frac{\partial \Phi_g}{\partial p_B^*} &= -\Phi_g^2 \frac{(1-\pi)(1-q)}{\pi q} < 0, \\
\frac{\partial \Phi_b}{\partial p_B^*} &= -\Phi_b^2 \frac{(1-\pi)q}{\pi(1-q)} < 0.
\end{aligned}$$

It follows that $\partial\Omega/\partial p_B^* < 0$. Proposition 4 shows that if $\pi < \underline{\pi}(p_B^o, q)$, then the firm will take less risk for higher accounting information precision, i.e., $dp_B^*/dq > 0$. In this case, the ex-ante probability of creditor turnover is strictly negative.

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