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Publication date:
2013

[Link to publication](#)

Citation for published version (APA):

Stenzel, A., & Wagner, W. B. (2013). *Asset Opacity and Liquidity*. (EBC Discussion Paper; Vol. 2013-012). EBC.

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Discussion paper

ASSET OPACITY AND LIQUIDITY

BY

Andre Stenzel, Wolf Wagner

1 NOVEMBER, 2013

**EUROPEAN BANKING CENTER DISCUSSION
PAPER
NO. 2013-012**

**THIS IS ALSO A CENTER DISCUSSION PAPER
NO. 2013-066**

ISSN 0924-7815

Asset Opacity and Liquidity

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November 1, 2013

Abstract

We consider a model of private information acquisition in which the cost of information depends on an asset's opacity. The model generates a hump-shaped relationship between opacity and the equilibrium amount of private information. In particular, the incentives to acquire information are largest for assets of intermediate opacity; such assets hence display low liquidity in the secondary market due to adverse selection. We also show that costly information acquisition generates incentives to source more correlated assets in the economy, as correlation reduces duplication of information costs. Our findings have implications for the design of financial regulation which aim at promoting transparency and reducing correlation in the financial system.

Keywords: endogenous information acquisition, opacity, asset liquidity

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1 Introduction

Opacity and illiquidity played a key role in the crisis of 2007-2009. During this period, trading in many assets was severely impeded. Investors generally had difficulties ascertaining the values of securitized assets and some markets experienced complete freezes. Illiquidity at the asset level quickly spread to financial institutions as such institutions were holders of the assets. Interestingly, some asset classes (and institutions) were more affected than others, raising questions about the underlying structural differences.

From the perspective of financial development, this recent experience with opacity and illiquidity is puzzling. Information availability had improved tremendously due to advances in information technology in the decades before the crisis. Furthermore, there were significant improvements in financial market infrastructure. Opacity should thus have fallen and – by conventional wisdom – boosted liquidity in the financial system. The fact that this did not happen points to the endogenous nature of opacity and liquidity. In particular, the properties of assets have to be evaluated in equilibrium and may critically depend on the incentives of investors to acquire information about them.

This paper studies the relation between the opacity of an asset and its liquidity. Our key idea is that the cost of information acquisition depends on an asset's opacity. For instance, acquiring complete information about an intransparent asset is more difficult than about an asset with a pay-off structure that is fairly known. The link to liquidity then arises from a mechanism emphasized by recent contributions (e.g., Dang et al. [2013a] and Yang [2012]) that have analyzed the *informational sensitivity* of securities: creating securities that provide investors with large gains from private information may be undesirable as this results in asymmetric information and hence may lower liquidity in secondary markets. We use this mechanism to analyze the impact of an asset's opacity, defined as public knowledge of the distribution of an asset's pay-offs.¹

We consider the following setup. There is an asset that pays off in a subset of states of the world. While the size of this subset is publicly known, there is incomplete knowledge about in which states of the world pay-offs materialize. The owner of the asset (a bank or firm) decides about the opacity of the asset by releasing information about the pay-off

¹This is different from security design, which affects the pay-off of the asset itself. Another departure from prior literature is that in our setting the cost and extent of information acquisition are both endogenous (the closest analysis in this respect is Yang [2012] who considers flexible information acquisition in the context of security design).

states.² A more transparent asset is one for which the public has more knowledge about the states of the world in which the asset pays out (a completely transparent asset is one where it is precisely known when the asset pays off and when not). Note that opacity neither alters the expected return nor the variance of the asset's pay-offs.

Following the opacity decision (which is public knowledge), the owner sells the asset to an investor. The investor can subsequently acquire private information about the asset, at a cost. For this the investor decides on a set of potential pay-off states she wants to "inspect". For each inspected state, the investor finds out whether the asset pays off in this state or not. Crucially, the total cost the investor suffers increases in the number of states that she inspects. In the last stage of the game, the investor may be hit by a shock that forces her to sell. At the same time, the state of the world becomes known to the public. This creates an adverse selection problem: market participants may suspect that investors sells because she has negative information about the asset even if the true reason is the liquidity shock. They thus lower the price for the asset and reducing the investors' utility (information acquisition is thus ultimately self-defeating).

A key result of the model is that there is a hump-shape relationship between opacity and information acquisition (and hence a U-shape relationship with secondary market liquidity). For a very transparent asset there is obviously no reason to acquire private information (as everything is already publicly known). Thus, the asset will be liquid. For a sufficiently opaque asset, an investor will also not acquire private information. This is because there are then many states that she would need to inspect, making the informational gain for each state low. Intermediate levels of opacity are by contrast most susceptible to information acquisition, resulting in low liquidity. At intermediate levels of opacity, information acquisition is also interior, resulting in the investor acquiring more (less) information when the asset opacity increases (decreases).

We also show that the investor's information acquisition problem affects an issuer's incentives to sell correlated or uncorrelated assets (or, alternatively, to source such assets). The incentives to acquire information are particularly high for correlated assets because learning about one asset then also provides information about other assets. Since information acquisition is efficiency-reducing in equilibrium, this suggests that an issuer will only obtain a relatively low price from the investor if he sell such assets. However, there is also

²An alternative interpretation is that the owner can source projects of varying opacity that he sells on later (consider for instance a bank that can lend to more or less opaque industries).

a countervailing effect. When a set of relatively heterogenous (that is, uncorrelated) assets is sold, investors will need to spend resources on information acquisition on each asset in isolation. This results in higher efficiency losses for a given amount of information acquisition per asset. This second effect can dominate, and give incentives for issuers to sell (or source) correlated assets.³

Our results inform the debate on regulation that aims at increasing transparency in the financial system. This debate typically presumes that transparency and liquidity are the same thing. Our analysis emphasizes the endogenous nature of liquidity and its non-monotonic dependence on transparency. In particular, (forced) increases in transparency can lower asset liquidity by leading to a more asymmetric distribution of information across agents in the financial system. Our results in fact suggest an “all-or nothing” approach: assets should either be made very transparent, or so opaque that they deter information acquisition.

1.1 Related Literature

The idea that the design of a security affects market participants’ incentives to acquire information has received considerable attention by the literature. Recent contributions by Dang et al. [2013a], Farhi and Tirole [2013] and Yang [2012] focus on the interaction of the security design and information acquisition incentives. One of the main themes is the optimality of (standard) debt: Because debt pays according to the limited liability constraint up until the face value (and then has a flat payoff curve), it minimizes the benefits from acquiring private information.

Dang et al. [2013a] formally introduce the concept of the *information sensitivity of a security* and show in a model of strategic security design and multiple trading rounds that debt contracts minimize market participants’ incentives to acquire information. Yang [2012] similarly finds standard debt to be least sensitive to private information. His results are more general in that they hold irrespective of the composition of the underlying asset pool. Farhi and Tirole [2013] consider a security trading game with a binary state of nature and highlight the importance of commonality of information: To ensure liquidity of an asset, it is optimal for potential trading partners to be symmetrically informed. This can be achieved

³This provides an explanation for the tendency of issuers to sell a pool of correlated assets, which flies in the face of diversification and has been named as one of the “puzzles of securitization” (Gorton and Metrick [2012]).

either by common knowledge or by common ignorance. Opacity in our paper leads to symmetric ignorance whereas very transparent assets mechanically preserve symmetry of information by ensuring that all parties are equally informed. Intermediate levels of opacity, however, lead to one-sided information acquisition and cause adverse selection problems.

Recent literature has also shown direct interest in understanding asset opacity. Kaplan [2006] analyzes a bank's choice of whether to release information about its risky assets to depositors at an interim stage, assuming that it can ex-ante commit to such a strategy. The paper shows that it can be efficient to keep information secret despite being this forcing the bank to offer non-contingent deposit contracts. The reason is that not revealing precludes the negative effects from revealing bad interim information, which are more severe than the benefits of good interim information. Other arguments for why opacity may be beneficial for the financial system are given by Cordella and Yeyati [2002] and Fecht and Wagner [2007]. Cordella and Yeyati [2002] show that when investors are less informed about bank assets, banks may be more stable. Fecht and Wagner [2007] in turn argue that asset opacity may be needed to provide bank managers with rents that induce efficient monitoring.

Pagano and Volpin [2012] analyze a model where investors differ in their ability to process information. They show that releasing information about securitized assets induces a trade-off. Information may decrease primary market liquidity because it induces a "winner's curse" problem for unsophisticated investors who cannot parse this information. At the same time, information increases secondary market liquidity because any information which is not released leaves scope for private information acquisition and hence adverse selection.

Carlin et al. [2013] focus on a similar issue in an experimental study. They vary the complexity of an asset in the sense of the computational difficulty required to obtain information about its payoff. They find that more complex assets induce a change in subjects' bidding strategies and lead to lower liquidity. Moreover, these changes do not occur (to the same extent) whenever uncertainty about private values is introduced instead of complexity of calculations. If subjects are aware that other subjects are potentially more adept at performing the required calculations, this can hence lead to a lack of (anticipated) commonality of information and hence adverse selection.

The papers by Monnet and Quintin [2013] and Dang et al. [2013b] are also closely related to the present work. These papers share as a common feature that transparency, i.e. more information, leads to efficient interim decisions at the cost of losses if investors are forced to

liquidate their positions. The common friction is the (lack) of depth in the secondary market. If the secondary market is too shallow, liquidation even after good interim information is subject to cash-in-the-market pricing. Hence, the benefits from good interim information cannot fully be capitalized upon whereas the losses from bad information are fully incurred. By reducing transparency (and conversely increasing opacity), this problem is mitigated at the cost of allocative efficiency. A similar problem of constrained endowments is analyzed in a security design context by Stenzel [2013]. He finds that (complex) securities composed of debt-like tranches are optimal by minimizing the security’s susceptibility to interim public information.

Dang et al. [2013b] also show that a diversified portfolio helps hiding information because it discourages private information acquisition. However, they analyze the case of a fixed cost of information acquisition which is independent of the security design. Our model, in contrast, considers an endogenous extent of information acquisition. This enables us to show that while incentives to acquire information are indeed lower in the case of uncorrelated assets, correlated assets may minimize the extent of private information production and may thus be preferred.

2 Model Setup

The economy consists of three (risk-neutral) agents, an owner of an asset O , an investor I (who is potentially subject to a Diamond–Dybvig liquidity shock), and an agent M representing the market. There are 3 periods, $t = 0, 1, 2$. Agents’ utilities are assumed to be additively separable and given as follows (C_t^i denotes consumption of agent i at period t):

- The owner O wants to consume in period 0. This can for example stem from a need for cash to realize other (profitable) ventures: $U^O = C_0^O$
- The investor I is patient with probability π or impatient with probability $(1 - \pi)$. If I is patient, utility is given by $U^{I,P} = C_0^{I,P} + C_1^{I,P} + C_2^{I,P}$, if impatient, utility is given by $U^{I,I} = C_0^{I,I} + C_1^{I,I}$. It is private information whether I is patient or not.
- The representative market agent is willing to shift consumption between periods 1 and 2: $U^M = C_1^M + C_2^M$

There are $n \in \mathbb{R}_+$ states of the world; the distribution over the states is uniform (i.e., letting $f(\cdot)$ be the density, $f(s) = \frac{1}{n}$ for all $s \in [0, n]$). At $t = 0$, the owner is in possession of a collection of assets or a project which pays out in l states of the world. We normalize the payoff in the l payoff-states to 1. The payoff accrues at $t = 2$ and is verifiable, i.e. can be contracted upon. The states in which it pays off are assumed to be known by the owner but not by any of the other agents; the set of payoff-states is denoted by $L \subseteq [0, n]$.⁴ The owner has no other assets.

The investor, irrespective of whether she is patient or impatient, has endowment ω^I at $t = 0$ and no other endowments. ω^I is assumed to be large in the sense that it exceeds the expected value of the collection of assets, $\omega^I \geq \frac{l}{n}$. Similarly, the market has an endowment ω^M at $t = 1$ and no other endowments; ω^M is likewise assumed to be large enough: $\omega^M \geq 1$.⁵

It is natural from the allocation of endowments that gains from trade can be realized: The owner should sell its assets to the investor at $t = 0$. Then, if the investor turns out to be impatient, she should in turn exchange the assets for M 's endowment at $t = 1$.

In the first stage, the owner has to decide about the *opacity* of the asset-backed securitized asset she designs (and issues) at $t = 0$. Formally, she chooses any $o \in \mathbb{R}_+ : l \leq o \leq n$ denoting the opacity level. This corresponds to choosing $O \subseteq [0, n]$ with $|O| = o$ and $L \subseteq O$, i.e. a subset O of o possible states which include the set of payoff states L . The reasoning behind this is as follows: Since only the owner knows the states of the world in which the asset pays out, all other agents attach $\frac{l}{n}$ as the probability that assets with maximum opacity $o = n$ pay out in a given state. If $o < n$, a mass $n - o$ states are ruled out; as such, all market participants know that the securitized asset pays out in l of the o states declared by the bank. Hence, the larger opacity, the less is known about payoff characteristics. Note that opacity does not affect the expected pay-off of the asset, which

⁴It is not essential for our model that the owner knows the set of payoff states. What is necessary is only that the owner is restricted in its choice of opacity (see below) to always include the payoff states.

⁵The lower bounds $\frac{l}{n}$ and 1 differ because of the timing of the trading game (see below). At the second trading stage where the market (potentially) acquires the securitized asset from the investor, public information may have been realized which increases the (conditional) expected value to 1. In particular, this occurs when it is common knowledge that a payoff state has been realized. As noted previously, we thus abstract from issues as in Dang et al. [2013b], where endowments can be a constraint, potentially leading to cash-in-the-market pricing. Abstracting from this additional friction biases our results against opacity: Opaque assets would have the additional (positive) effect of decreasing the gain from good information and be thus more desirable than less opaque ones where the endowment constraint would be more likely to bind.

is $\frac{l}{n}$. Denote by $c(n - o)$ the costs or benefits associated with the choice of an opacity level o .

Furthermore, at date $t = 1$, the investor has the opportunity to acquire information about the payoff characteristics of the assets. Her technology is as follows: By investing $k \cdot a > 0$, the investor rules out a mass a , $0 \leq a \leq o - l$ of states in which the securitized asset does not pay out. Hence, the opacity of the securitized asset is reduced; this reduction, however, is private information to I .⁶

The bargaining mode in the trading stages is as follows: The owner has all the bargaining power at $t = 0$, i.e. she makes a take-it-or-leave-it offer to the investor. At $t = 1$, the investor can decide to trade the asset to the market. We model the market as competitive in the following manner: The investor decides whether to offer the assets it holds to the market. If the asset is offered, trade takes place at a price equal to the posterior belief of M about the value of the asset where beliefs (about both the level of private opacity of I and about which types of investor offer) have to satisfy Bayesian updating.⁷ Information acquisition by the investor takes place before the realization of the state of the world and before the investor knows whether she is patient or impatient.

To sum up, the timeline of the model in extensive form is as follows:

$t = 0.0$: the owner chooses o with $l \leq o \leq n$

$t = 0.1$: the owner offers an asset-backed securitized asset characterized by o to the investor

$t = 0.2$: the investor accepts or not

$t = 1.0$: the investor decides on information acquisition

$t = 1.1$: the true state of the world is revealed

$t = 1.2$: the investor learns whether she is patient or not

$t = 1.3$: the investor may trade the securitized asset to the market for the competitive price

⁶Note that the information acquisition process is hence deterministic, which simplifies the analysis considerably. In an extension we consider alternatively that the investor acquires information state-by-state, with random discovery of payoff states. This modification does not affect our main results.

⁷This is equivalent to a trading protocol where the market is composed of identical competitive agents who place limit orders to buy the asset and where the investor decides whether to execute the (highest) order or not.

$t = 2.0$: the assets and thus also the securitized asset pays out (if the state of the world falls in the payoff domain)

We restrict attention to pure strategy equilibria.

To facilitate the further analysis, we reorder the states of the world as follows. Denote the set of payoff states by $[0, l] = L$ and denote by $[0, o] = O$ the set of potential payoff states as chosen by the owner. Furthermore, let analyzing a mass a of states reduce the interval of potential payoff states to $[0, o - a]$. This relabeling is without loss of generality and leads to the following classification: If $s > o$, the state of the world falls outside the public domain and all agents know that the asset does not pay. If $s \in (o - a, o]$, the investor privately knows that the asset does not pay, while the market only notices that $s \leq o$, i.e. that s is in the set of potential payoff states. If $s \in (l, o - a]$, the state of the world is such that the securitized asset does not pay. For $s \leq l$, the asset pays. However, neither the investor nor the market are able to make this distinction; whenever $s \leq o - a$, the investor only knows that the state of the world is in her private domain (and thus that the probability of the asset paying is $\frac{l}{o-a}$). Likewise, the market only infers that $s \leq o$.

3 Asset Trade

To solve for an equilibrium of the game, we first solve for the equilibrium at the final trading stage ($t = 1.3$) where the investor decides whether to offer her asset to the market. At this stage, asset opacity o and the state of the world s are common knowledge. Furthermore, the investor has potentially acquired information a (his private domain is thus $[0, o - a]$). The market holds beliefs \tilde{a} about the extent of information acquisition of the investor. We assume that the investor has a weak preference for selling when she is impatient, and a weak preference for not selling when she is patient.⁸

The case of $s > o$ is uninteresting. Both investor and market know that the securitized asset does not pay off. The shadow price of the asset is hence zero, and it is irrelevant whether trades take place.

Consider next that $s \leq o$. If an investor is impatient, she will sell regardless of price (given her weak preference for selling) since there is no utility from holding on to the asset. For a patient investor, her decision to sell may depend on whether the signal is in her private

⁸This rules out equilibria where trade never takes place. These equilibria would exist otherwise but do not survive standard refinements such as the Intuitive Criterion.

domain $[0, o - a]$. Suppose first that the signal is outside her private domain ($s > o - a$). The investor then knows that the asset is worthless, and she will hence sell regardless of the price. Suppose next that the signal is inside the private domain ($s \leq o - a$). The investor's expected utility of holding on to the securitized asset is thus $\frac{l}{o-a}$. Taking into account the weak preference for holding on to the asset, she will hence offer the securitized asset if and only if the price is strictly larger than $\frac{l}{o-a}$. Such a price, however, cannot prevail in an equilibrium of the full game: Even if only investors who observe a positive private signal, i.e. that $s \leq o - a$ falls in their private domain, decide to offer, the conditional expected value M would attach to the securitized asset is $\frac{l}{o-\tilde{a}}$. In an equilibrium of the full game, however, $\tilde{a} = a$ has to hold. $\frac{l}{o-a}$ thus constitutes an upper bound for the expected payoff of the securitized asset.

We can summarize the results as follows:⁹

Lemma 1 *The unique equilibrium in the trading stage is:*

- i) If the investor is impatient, she always offers.*
- ii) If the investor is patient, she offers if and only if the state is outside her private domain but within the public domain ($s \in (o - a, o]$).*

We next solve for the price at which assets are sold (in the case of $s \leq o$), which is equal to the expected value conditional on observing that an asset was offered given beliefs \tilde{a} .

This expected value can be derived as follows. With probability $(1 - \pi)$, the investor is impatient and hence offers by Lemma 1. In this case, the expected value of the securitized asset is $\frac{l}{o}$. Furthermore, an offer is made if the investor is patient and the signal is outside her private domain. Given beliefs \tilde{a} about the extent of private information acquisition, this occurs with probability $\pi \frac{\tilde{a}}{o}$. In this case the securitized asset is worthless. The expected value of the securitized asset (conditional on being offered) is hence $\frac{(1-\pi)\frac{l}{o}}{1-\pi+\pi\frac{\tilde{a}}{o}}$. Rearranging gives for the price of the securitized asset

$$p(\tilde{a}, o) = \frac{1 - \pi}{o - \pi(o - \tilde{a})} l. \quad (1)$$

Note that for $\tilde{a} = 0$ (that is, if the market believes there is no information acquisition), we have that $p = \frac{l}{o}$ as M believes that there is no adverse selection. Moreover, note that $p'(\tilde{a}) < 0$. If the market believes that more information acquisition has taken place, it also believes that the adverse selection problem is more severe. Hence, a lower price is paid.

⁹A more formal derivation of the offer stage equilibrium is given in appendix A.1.

4 Information Acquisition Stage

This section analyzes the information acquisition stage. At this stage, the investor knows (common) opacity o and chooses $a \in [0, o - l]$.

Let us consider an equilibrium candidate a^* and corresponding market beliefs \tilde{a} . In order for a^* to form an equilibrium, it has to be the case that the investor cannot improve her utility by deviating to \hat{a} . At the information acquisition stage, a^* therefore constitutes an equilibrium level of information acquisition if and only if

$$\forall \hat{a} \in [0, o - l] : u(a^*, a^*) \geq u(\hat{a}, a^*),$$

where $u(a, \tilde{a})$ denotes the investor's expected utility given that she chooses information acquisition extent a and the market holds beliefs \tilde{a} .

Utility $u(a, \tilde{a})$ is derived as follows. In case the state of the world falls outside the public domain ($s > o$), the investor does not derive any utility from owning the asset as it is common knowledge that the asset is worthless. In case the state falls inside the public domain ($s \leq o$), which occurs with probability $\frac{o}{n}$, she either sells or holds onto the asset. She sells whenever she is impatient or when the state is outside her private domain ($s \in (o - a, o]$). In this case she obtains $p(\tilde{a}, o)$. When she is patient and the state is inside the private domain ($s \in [0, o - a]$), she (in expectation) obtains utility $\frac{l}{o-a}$ by waiting for the asset return to materialize. Finally, the investor incurs information acquisition costs $k \cdot a$. Summarizing, we thus obtain for the investor's utility:

$$u(a, \tilde{a}) = \frac{o}{n} \left((1 - \pi + \pi \frac{a}{o}) p(\tilde{a}, o) + \pi \frac{o - a}{o} \frac{l}{o - a} \right) - k \cdot a. \quad (2)$$

Note that for $\tilde{a} = a$, i.e. whenever beliefs correspond to the true private opacity level, the above simplifies to $\frac{l}{n} - k \cdot a$.

This enables us to derive the investor's optimal level of information acquisition, a^* , for given market beliefs, \tilde{a} . The derivative of $u(a, \tilde{a})$ with respect to a is

$$\frac{\partial u(a, \tilde{a})}{\partial a} = \frac{\pi}{n} p(\tilde{a}, o) - k. \quad (3)$$

Equation (3) shows that information acquisition trades off the costs, k , with the expected benefits $\frac{\pi}{n} p(\tilde{a}, o)$. The benefits are determined as follows: By acquiring information about a states, these a states are ruled out as potential payoff states. With probability $\frac{a}{n}$ one such state will realize at $t = 1.1$. If the investor is patient (occurring with probability π), she

can then sell the asset at price $p(\tilde{a}, o)$, rather than holding onto an asset that is worthless. Because both the gains and costs are linear in the amount of information acquisition, we have the above trade-off. There are hence three cases to consider. If $\frac{\pi}{n}p(\tilde{a}, o) - k > 0$ (or rearranging, if $p(\tilde{a}, o) < \frac{kn}{\pi}$), the smallest possible information acquisition ($a^* = 0$) will maximize investor utility. Likewise, if $\frac{\pi}{n}p(\tilde{a}, o) - k = 0$ ($p(\tilde{a}, o) = \frac{kn}{\pi}$), the highest possible information acquisition ($a^* = o - l$) maximizes utility. Finally, if $p(\tilde{a}, o) = \frac{kn}{\pi}$, the investor is indifferent as to which opacity level to choose. We summarize

$$\operatorname{argmax}_{a \in [0, o-l]} u(a, \tilde{a}) = \begin{cases} 0 & \text{if } p(\tilde{a}, o) < \frac{kn}{\pi} \\ [0, o-l] & \text{if } p(\tilde{a}, o) = \frac{kn}{\pi} \\ o-l & \text{if } p(\tilde{a}, o) > \frac{kn}{\pi}. \end{cases} \quad (4)$$

The intuition for why the optimal information acquisition depends on the price p is the following. The benefit from higher information acquisition is that there are more states of the world in which the investor has private information that the asset does not pay off. If such a state materializes, a patient investor will sell the asset and obtain p instead of nothing (the securitized asset is worthless). Note that an increase in opacity o reduces the price p (given the same beliefs \tilde{a}) and thus makes information acquisition less attractive.

Recall that an equilibrium of the full game requires beliefs to satisfy Bayesian updating, i.e. $a^* = \tilde{a}$. Define \underline{o} as the critical opacity level that leads to full information acquisition. We obtain $\underline{o} = \pi l + \frac{\pi(1-\pi)l}{kn}$ by rearranging $p(o-l, \underline{o}) = \frac{kn}{\pi}$. For any o equal or lower than \underline{o} , full information acquisition is induced. Likewise, define \bar{o} as the critical opacity level which completely deters information acquisition. We obtain $\bar{o} = \frac{\pi l}{kn}$ by rearranging $p(0, \bar{o}) = \frac{kn}{\pi}$, respectively. For o larger or equal than \bar{o} , there is hence no information acquisition. We assume in the following that $\pi \geq kn$, which guarantees $\underline{o} \leq \bar{o}$ (this assumption is innocuous as for $\pi < kn$ there would never be any information acquisition irrespective of the level of o as p is bounded by 1). For intermediate values of o , an interior equilibrium arises. By solving for \tilde{a} in the condition $p(\tilde{a}, \tilde{a}) = \frac{kn}{\pi}$, we obtain for the interior equilibrium that $\tilde{a} = a^* = \frac{(1-\pi)}{\pi} \left[\frac{\pi l}{kn} - o \right]$.

We can summarize

Proposition 1 *The equilibrium level of information acquisition a^* for given initial opacity*

o is

$$a^*(o) = \begin{cases} 0 & \text{if } o \geq \bar{o} \\ \frac{(1-\pi)}{\pi} \left[\frac{\pi l}{kn} - o \right] & \text{if } o \in (\underline{o}, \bar{o}) \\ l & \text{if } o \leq \underline{o} \end{cases} \quad (5)$$

with $\underline{o} = \pi l + \frac{(1-\pi)\pi l}{kn}$ and $\bar{o} = \frac{\pi l}{kn}$.

Proposition 1 shows that equilibrium information acquisition depends on asset opacity o . High levels of opacity o lead to low incentives to acquire private information. As seen above, this is due to the fact that gains from information acquisition are realized only if a state of nature which has been ruled out as a payoff-state candidate is realized *conditional on s falling in the public domain*, i.e. $s \in [0, o]$. This conditional probability is given by $\frac{o}{\bar{o}}$ if a states have been ruled out. As a result, for sufficiently high o , information acquisition can always be deterred. Likewise, for sufficiently low o , all information is acquired. For intermediate levels of opacity $o \in (\underline{o}, \bar{o})$, there is an interior amount of information acquisition.

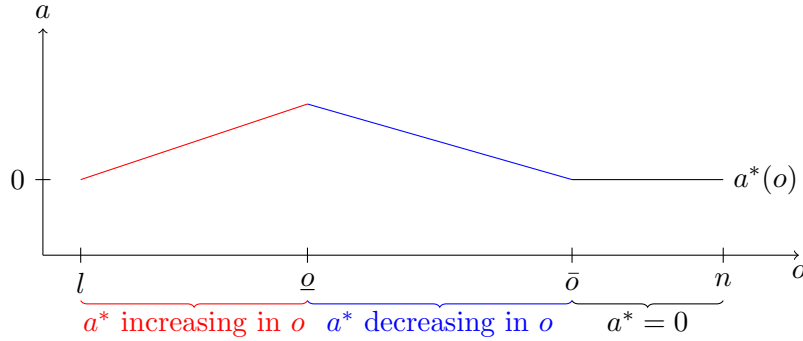


Figure 1: Information Acquisition as a Function of o

Figure 1 shows how equilibrium information acquisition a^* depends on o (for this we assume $l < \underline{o}$ and $\bar{o} < n$, such that all possible cases can materialize). For $o > \bar{o}$, information acquisition can be deterred and hence $a^* = 0$. For $o \in (\underline{o}, \bar{o})$ we get incomplete information acquisition. In this range, information acquisition is decreasing in opacity since $a^*(o) = \frac{(1-\pi)}{\pi} \left[\frac{\pi l}{kn} - o \right]$ is decreasing in o . Information acquisition is maximized at \underline{o} when all information is acquired. A further decline in opacity below \underline{o} (mechanically) reduces information acquisition by the investor as information acquisition is bounded by $o - l$. At the extreme, when the owner sells a completely transparent securitized asset ($o = l$), no information acquisition can be acquired.

5 Optimal Opacity Choice

In this section, we analyze the owner's choice of opacity (at $t = 0.0$). Since, by assumption, the owner extracts the entire surplus in the economy, this choice will also maximize welfare in the economy.

Welfare in the economy consists of i) the investor's gains from owning the asset net of information acquisition costs, $u(a, \tilde{a})$, ii) the cost of opacity reduction for the owner, $c(n - o)$. We assume that the owner's cost of opacity reduction are linear in $(n - o)$ and given by $c(n - o) = k_o \cdot (n - o)$. The market can be ignored in the welfare calculation as it breaks even on average. We thus have for welfare, and hence also the utility of the owner:

$$W(o, a^*(o)) = u(a^*(o), a^*(o)) - k_o \cdot (n - o). \quad (6)$$

Using that in equilibrium $\tilde{a} = a^*(o)$, (1) yields $p(\tilde{a}, o) = p(o) = \frac{1-\pi}{o-\pi(o-a^*(o))}l$. Thus, welfare can be expressed as:

$$W(o, a^*(o)) = \frac{l}{n} - k_o \cdot (n - o) - k \cdot a^*(o). \quad (7)$$

Welfare thus consists of the expected fundamental return on the asset, $\frac{l}{n}$, net of the cost of opacity reduction by the owner and information acquisition costs by the investor. Any adverse selection is in equilibrium anticipated by the market (and the price adjusted accordingly). The owner's choice of opacity therefore has two effects. First, it directly affects the cost of opacity reduction, $k_o \cdot (n - o)$. Second, the opacity choice affects equilibrium information acquisition, $a^*(o)$, and hence information acquisition costs by the investor. The owner problem is thus simply to minimize the total costs of opacity reduction and information acquisition in the economy.¹⁰ Note that for $k_o = 0$, the optimization boils down to minimizing information acquisition by the investor. Note, in addition, that in equilibrium there are always gains from trade between the owner and the investor. This is because the investor can secure herself a strictly positive utility by not acquiring any information. Hence the asset has a strictly positive value for the investor and since the owner only consumes at $t = 0$, trade will hence take place a positive price.

¹⁰If the owner can extract only a part of the surplus generated for the investor, there is a wedge between welfare and the owner's utility. If information acquisition cannot be avoided in equilibrium, optimization will then result in excess opacity (and thus excess private information acquisition) compared to the first best.

Two cases arise. If the original asset is sufficiently opaque such that information acquisition can be deterred ($n \geq \bar{o}$), it is optimal for the owner to not reduce opacity at all ($a^*(n) = 0$). In this case, neither owner nor investor will incur any costs. If this is not possible ($n < \bar{o}$), the owner's problem can be broken down as follows: First, an opacity level in the range of $[\underline{o}, n)$ is never chosen. Such an opacity level will be dominated by choosing $o = n$, which will lead to lower information acquisition by the investor (recall that information acquisition is decreasing in opacity in the interior range) and also does not incur any opacity reduction costs. Second, by choosing an opacity level o from $[l, \underline{o}]$, any residual opacity will be fully eliminated by the investor ($a^*(o) = o - l$). In this case welfare is

$$W(o, a^*(o)) = \frac{l}{n} - ka^*(o) - k_o \cdot (n - o). \quad (8)$$

The optimal choice in this region thus depends on k and k_o . If $k \leq k_o$, the (weakly) optimal choice within $[l, \underline{o}]$ is $o = \underline{o}$. However, $o = \underline{o}$ is dominated by $o = n$, as previously discussed. If $k > k_o$, the optimal choice in the region is $o = l$. In order to find the global maximum, the owner thus has to compare welfare at the two extreme opacity levels ($o = l$ and $o = n$). This boils down to comparing the cost of fully eliminating opacity, $k_o \cdot (n - l)$, with the cost of investor information acquisition that arises for a completely opaque securitized asset, $k \cdot a^*(n)$.

This leads to the following proposition:

Proposition 2 *The owner sells a completely opaque asset ($o^* = n$) if*

(i) this deters information acquisition ($n \geq \bar{o}$), or

(ii) $k \cdot a^(n) < k_o \cdot (n - l)$.*

Otherwise, the owner chooses to sell a fully transparent asset ($o^ = l$).*

There are three important messages here. First, it can be optimal to sell an opaque securitized asset. This is because such a securitized asset deters information acquisition by investors and in addition directly lowers cost for the owner arising from credibly providing information about the securitized asset to investors. Second, intermediate levels of opacity are the least desirable. For such opacity levels, the investor incurs information acquisition costs and the owner has to bear the cost of opacity reduction. Intermediate opacity levels are in particular dominated by full opacity, which results in lower information acquisition and requires lower opacity reduction. Third, if the costs of opacity reduction are sufficiently

small, it can be optimal for the owner to eliminate all opacity because this (mechanically) avoids information acquisition costs by the investor.

One way to assess these prediction empirically is to relate measures of opacity, such as rating splits (c.f. Morgan [2002]), to market liquidity as measured for example by bid-ask spreads.

6 Discussion

6.1 Random Discovery of the Payoff Interval

The analysis in the baseline model was significantly simplified because we considered information acquisition to be *deterministic* in that if an investor decides to spend more resources, she rules out states of the world in which the asset does not pay off with certainty. Alternatively, discovery of the pay-off interval may be stochastic. In particular, the investor may decide to analyze a specific state and then find out whether the asset pays off in this state or not. Following this, she may decide to acquire information about more states. A consequence is that the extent to which opacity is eliminated becomes random: the investor may be lucky and discover the payoff interval early on or she may be unsuccessful and decide to stop after having acquired a certain amount of information. Another consequence is that the amount spent on information acquisition will be stochastic as well.

The case of random state discovery is analyzed in detail in appendix A.2. The basic results from the baseline model carry over. In particular, it can be shown that there can still be an interior equilibrium such that an investor acquires information only up to a certain amount. In addition, (expected) information costs can still be reduced by selling assets of higher opacity.

6.2 Different Information Acquisition Costs

We have assumed that the costs of information acquisition are linear in the number of states that are analyzed. An alternative assumption is that the (marginal) cost of information acquisition is increasing in the number of analyzed states. Such a cost structure would arise if different states are associated with different costs (it might be easier to understand, for instance, the exposure of an asset to the oil price than for instance to a general change in the level of inflation). In this case, the investor would first decide to discover information

about the “cheaper” states, leading to increasing acquisition costs. Increasing information acquisition costs strengthen the role for an interior equilibrium. Nevertheless, the same qualitative results obtain: sufficiently high opacity can deter information acquisition and information acquisition is decreasing in opacity at any interior equilibrium (see appendix A.3).¹¹

It is critical, however, that the cost of opacity reduction is incurred per state. Consider for instance that there are fixed costs K of eliminating all opacity (regardless of the extent of opacity o) and let us look at the incentives for an investor to acquire information given that the market holds beliefs $\tilde{a} = 0$. Replacing $k \cdot a$ with K in equation (2) we obtain

$$u(o - l, o) - u(0, o) = K - \frac{\pi}{n}(o - l)p(0, o) = K - \frac{\pi}{n}\left(1 - \frac{l}{o}\right)l. \quad (9)$$

The incentives to acquire information are now increasing in opacity: higher opacity means that a single information acquisition that eliminates all opacity is more effective because it pays in more states. In fact, this corresponds to the technology of information acquisition of Dang et al. [2013a] and Dang et al. [2013b].

6.3 Discovering Loss States

The next variation we consider is one where information acquisition rules out pay-off states (instead of non-paying states as in the baseline model). Specifically, let us assume that the asset pays off on $[l, n]$ but not on $[0, l]$ (thus the exact opposite of the baseline model). Information acquisition is such that the investor learns about payoff states on $[l, o]$ and hence narrows down the set of states where the securitized asset does not pay.

Appendix A.4 analyzes this setting in detail. A key difference to the baseline model is that the gains from information acquisition are no longer decreasing in the market price. The reason is that information acquisition now increases the range where the investor has positive private information about the asset. If a state in this range materializes, she will refrain from selling, resulting in decreasing gains from information acquisition. A consequence is that the interior equilibrium may no longer exist and there is either no or full information acquisition. Nonetheless, opacity tends to reduce information acquisition, as in the baseline model.

¹¹It may be the case that “sufficiently high” nonetheless leads to an opacity level of $o < l$. For example, if $k_O(n - o) = 0$, it may be optimal for the owner to decrease opacity and rule out the “cheap” states as to avoid information acquisition, which would otherwise lead to positive information acquisition if $o = n$.

6.4 Different Utility for the Impatient Investor

In the baseline model, there is no direct cost to adverse selection at the trading stage. This is because the utility of early and late investors is the same, a lower market price does not affect welfare. In case impatient investors have higher marginal utility, this is no longer the case. Adverse selection will then reduce welfare by reducing the price impatient investors (with higher marginal utility) can obtain. As adverse selection arises from information acquisition, this strengthens the welfare implications of our model. This case is formally discussed in appendix A.5.

7 Optimal Portfolio Choice

The baseline model analyzes a situation where a bank can choose how much information to release about an asset it wants to sell. In this section we look at a different question: Suppose a bank wants to sell a portfolio of assets, which assets does it want to include this portfolio? This question is relevant in case the bank has already a collection of different assets but also when a bank considers sourcing new assets (for example, by extending new loans) for subsequent securitization.

7.1 Asset correlation

We first analyze the question of correlation of assets. We consider a bank intending to sell a pool of assets where the choice is whether to compose it of correlated or uncorrelated assets. When making this decision, the bank will consider how this will influence the incentives for the investor to acquire information.

We change the baseline model as follows. At $t = 0.0$ (instead of an opacity choice) the bank now chooses whether to sell x correlated or x uncorrelated assets ($x \geq 2$). Each asset on its own is identical to the one in the baseline model. Correlated assets, however, pay off in exactly the same states, while for uncorrelated assets the payoff states are independent. Information acquisition takes place on the asset level as well. The interdependence among assets (or lack thereof) has the following consequences for information acquisition. In the case of a correlated pool, it suffices for an investor to acquire information about one asset only – all information fully applies to the other assets as well. This not the case for uncorrelated pool, where information about one asset is not informative about other assets

at all. For such a pool, an investor has to acquire information about each asset in isolation.

Consider first the case of correlated assets. Since the investor can now apply information from one asset to in total x assets, the utility from information acquisition is (similar to equation (2)):

$$u(a, \tilde{a}) = x \cdot \frac{o}{n} \left((1 - \pi + \pi \frac{a}{o}) p(\tilde{a}, o) + \pi \frac{o - a}{o} \frac{l}{o - a} \right) - k \cdot a. \quad (10)$$

As in the baseline model, we can derive the resulting cases for optimal information acquisition:

$$a_C^* = \begin{cases} 0 & \text{if } o \geq \bar{o}_C \\ (1 - \pi)(x \frac{l}{kn} - \frac{o}{\pi}) & \text{if } o \in (\underline{o}_C, \bar{o}_C) \\ o - l & \text{if } o \leq \underline{o}_C \end{cases} . \quad (11)$$

where $\underline{o}_C = \pi l + x \frac{\pi(1-\pi)l}{kn}$ and $\bar{o}_C = x \frac{l\pi}{kn}$. Compared to the baseline model, information acquisition is now more likely: both the amount of information acquisition in the interior equilibrium, $a_C^* = (1 - \pi)(x \frac{l}{kn} - \frac{o}{\pi})$, as well as the threshold for which information acquisition can be completely deterred, $\bar{o}_C = x \frac{l\pi}{kn}$, are increasing in x . The intuition is simple: because information can be applied to more assets, it becomes more valuable and more of it tends to be acquired.

In the case of uncorrelated assets, each asset needs to be investigated separately. Asset level information acquisition a^* is hence the same as in the baseline model (Proposition 1). On the level of the pool, information acquisition is then $x \cdot a^*$.

We hence get the following trade-off. The incentives to acquire information for a given asset are stronger in the correlated pool. This makes it less desirable to sell such a pool because of the deadweight loss of the cost of information acquisition. However, for a given amount of information acquisition per asset, the costs are higher in the uncorrelated pool because there information has to be acquired about each asset individually.

This has consequences for the optimal pool composition: When information acquisition is sufficiently unattractive ($o \geq \bar{o}_C$), both correlated and uncorrelated pools avoid information acquisition. In this case an owner would be indifferent between either pool. If $o < \bar{o}_C$ but $o > \bar{o}$, information acquisition can be avoided for the uncorrelated pool (for which incentives to gather information are lower) but not for the correlated pool. In this case, an uncorrelated pool maximizes welfare. Next, when $o < \bar{o}$, information acquisition cannot be deterred for either pool. If $o > \underline{o}_C$ (that is, information is not fully acquired in the correlated pool), an uncorrelated pool still maximizes welfare (this can be seen by comparing

information acquisition in an interior equilibrium with correlated assets, $(1 - \pi)(x \frac{l}{kn} - \frac{o}{\pi})$, to the one in the uncorrelated pool, $x(1 - \pi)(\frac{l}{kn} - \frac{o}{\pi})$. However, for o that is sufficiently below \underline{o}_C , there will be so much information acquisition in the uncorrelated pool that the information costs in this pool dominate (information acquisition in the correlated pool does not change as it is already at its maximum $o - l$). The critical o at which this happens is determined by the condition $x(1 - \pi)(\frac{l}{kn} - \frac{o}{\pi}) = o - l$. Rearranging yields

$$\hat{o} = l \frac{x(1 - \pi) \frac{\pi}{kn} + 1}{x(1 - \pi) + 1}. \quad (12)$$

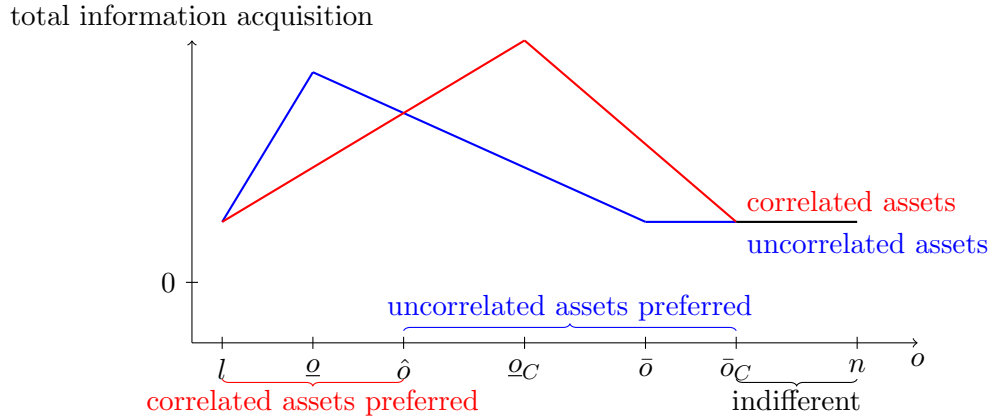


Figure 2: Information Acquisition as a Function of o

Figure 2 illustrates the equilibrium levels of total information acquisition. We can summarize:

Proposition 3 *Consider the choice of the owner to either sell correlated or uncorrelated assets.*

1. *If $o \geq \bar{o}_C$, the owner is indifferent between both pools.*
2. *If $o \in (\hat{o}, \bar{o}_C)$, the owner prefers to sell an uncorrelated pool of assets.*
3. *If $o \leq \hat{o}$, the owner prefers to sell a correlated pool of assets.*

Proposition 3 delivers the following (empirical) prediction: Asset pools with relatively high opacity (and hence low information acquisition incentives) should on average exhibit

less correlation. This is because for these types of asset pools, the lack of correlation may avoid information acquisition. Conversely, for transparent and hence more information sensitive asset pools, correlated asset pools should be preferred in order to avoid that information is gathered about assets multiple times.

7.2 Splitting Portfolios

The analysis above can also be used to understand an owner's incentives to pool assets or to sell them individually. In particular, consider the situation that a bank has an asset pool which pays x in l states. The bank can sell these assets in their entirety to an investor. Alternatively, it can split them up into x smaller assets (each paying 1 in l states) and sell them to x separate investors. The analysis is identical to the one above for correlated and uncorrelated assets. The incentives for an investor who holds the single asset to acquire information are high because any informational gain can be applied to an asset that pays off x (the gain is identical to the case of a correlated asset pool where the information could be applied to x assets that each pay one). The incentives for each individual investor who has acquired a split asset are low by contrast since each asset only pays in a payoff state. Presuming that investors do not communicate with each other about their information, there will hence be more information acquisition for the whole asset than for a split asset. However, any information acquired for a split asset is now acquired by x investors (in the similar way as an investor who wants to learn about an uncorrelated pool has to acquire information x times). This leads to precisely the same trade-off as above. Hence, it delivers the prediction that when the cost of information acquisition is not too high, it is optimal to sell assets separately in order to avoid information acquisition. However, when information acquisition is sufficiently attractive, investors will acquire sizeable information also about the split assets. Since information is acquired x -times for such assets, selling the asset pool in its entirety is then preferred.

8 Conclusion

This paper has considered the relationship between an asset's opacity, and the incentives of agents to acquire private information about it. We have shown that the relationship is a non-monotonic one. Both very transparent and very opaque assets preserve the commonality of information by avoiding information acquisition and resultant adverse selection. Such assets

can hence be expected to be liquid. Assets that display intermediate degrees of opacity in contrast are prone to information acquisition. Such assets may thus suffer from adverse selection problems in secondary markets. While the baseline model is fairly stylized, its predictions are robust to a variety of modifications.

Our results have important policy implications. Recent regulatory efforts have focused on increasing transparency in the financial system. Our analysis shows that doing this in an undifferentiated way is not necessarily desirable, for two reasons. First, reduced opacity increases the incentives to acquire information, and hence may render assets less liquid. Second, higher information acquisition increases the private incentives of issuers to source correlated assets, in order to avoid duplication of information acquisition in the economy. Higher correlation of exposures, in turn, may harm financial stability by increasing systemic risk.

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A Appendix

A.1 Offer Stage Equilibrium

Denote by μ the belief M attaches to the probability of an offer by patient investors who observe $s \leq o - a$. Furthermore, recall that all other investor types offer with probability 1 (because it is a strictly dominant strategy for them to do so). The expected value of a securitized asset \tilde{p} given beliefs μ and \tilde{a} can thus be expressed as

$$\tilde{p}(\tilde{a}, \mu) = \frac{l}{o - \tilde{a}} \cdot \Pr\{s \leq o - \tilde{a} | \text{offer}\} = \frac{l}{o - \tilde{a}} \cdot \frac{(1 - \pi) \frac{o - \tilde{a}}{o} + \pi \mu \frac{o - \tilde{a}}{o}}{(1 - \pi) + \pi \left[\mu \frac{o - \tilde{a}}{o} + (1 - \frac{o - \tilde{a}}{o}) \right]}. \quad (13)$$

In (13), the denominator $(1 - \pi) + \pi \left[\mu \frac{o - \tilde{a}}{o} + (1 - \frac{o - \tilde{a}}{o}) \right]$ reflects that M believes that all impatient investors, all patient investors with s outside their private domain and a fraction μ of patient investors with s in their private domain offer. The numerator $(1 - \pi) \frac{o - \tilde{a}}{o} + \pi \mu \frac{o - \tilde{a}}{o}$ in turn captures that the securitized asset holds value if and only if s falls in the private domain, i.e. $s \leq o$. Note that the price already reflects that $s \in O$ was observed; otherwise, it is common knowledge that the securitized asset holds no value. (13) can be simplified to

$$\tilde{p}(\tilde{a}, \mu) = l \frac{(1 - \pi) + \mu\pi}{o - (1 - \pi)(o - \tilde{a})}. \quad (14)$$

Note that upon offering, I receives $\tilde{p}(\tilde{a}, \mu)$ which implies that a patient investor with $s \in O^I$ is faced with the trade-off between

$$E[U^{\text{offer}}] = \tilde{p}(\tilde{a}, \mu) \text{ and } E[U^{\text{no offer}}] = \frac{l}{o - a}.$$

Any equilibrium of the offer stage game requires that μ coincides with the probability that a patient investor who observes s within her private domain offers *given beliefs* \tilde{a} . In an equilibrium of the whole game $\tilde{a} = a$ is additionally required. We restrict attention to pure strategy equilibria, i.e. consider whether equilibria with $\mu = 1$ (full offering) and/or $\mu = 0$ (partial offering) can be sustained. Lemma 2 shows that *full offering* can be sustained only for the case of $a = 0$, i.e. the case where no information has been acquired by I irrespective of beliefs \tilde{a} . Otherwise, only *partial offering* can be supported in the offer game; a sufficient condition to support such an equilibrium is the (reasonable) restriction of $\tilde{a} \geq 0$.

Lemma 2 *Suppose that M holds beliefs $0 \leq \tilde{a} \leq o - l$ at the offer stage.*

- i) An equilibrium where all types of investors offer can only be sustained for $a = 0$, irrespective of beliefs \tilde{a} .
- ii) If $a \geq 0$, one pure strategy equilibrium has $\mu = 0$ and thus the property that investors who are patient and observe $s \in O^I$ do not offer.

Proof:

i) Full offering requires

$$E[U^{\text{no offer}}] \leq E[U^{\text{offer}}] \Leftrightarrow \frac{l}{o-a} \leq \tilde{p}(\tilde{a}, 1) = \frac{l}{o} \Leftrightarrow o \leq o-a,$$

which is only possible for $a = 0$.

ii) Consider that $a > 0$ and $\tilde{a} \geq 0$ imply that

$$o-a < o \leq \frac{o-\pi(o-\tilde{a})}{1-\pi} \Rightarrow \frac{l}{o-a} > l \cdot \frac{(1-\pi)+0 \cdot \pi}{o-(1-\pi)(o-\tilde{a})} = \tilde{p}(\tilde{a}, 0) \Rightarrow E[U^{\text{no offer}}] > E[U^{\text{offer}}],$$

i.e. that partial offering can be sustained.

We restrict attention in our analysis to partial offering equilibria.¹² This allows to write the price exclusively as a function of \tilde{a} and o (as we have done in the main body of the text):

$$p(\tilde{a}, o) = \tilde{p}(\tilde{a}, 0) = \frac{1-\pi}{o-\pi(o-\tilde{a})}l. \quad (15)$$

A.2 Random Discovery of the Payoff Interval

In this extension we consider an alternative information acquisition technology that eliminates loss states stochastically. An investor who decides to spend more on information acquisition will now with a certain probability discover the payoff interval.

Specifically, let us consider the following information acquisition technology. Suppose there is a random variable Y that determines the *starting state* of the discovery process, with $Y \sim U[l, o]$. The investor knows the distribution of the random variable, but not its

¹²To support this, consider the following: If $\mu = 1$, the price M offers is independent of \tilde{a} . However, $a = 0$ is required for I to always offer, i.e. a prerequisite for $\mu = 1$. It seems reasonable (and supported by refinements) to only consider the full offering equilibrium where $\tilde{a} = a = 0$. However, this leads to outcome-equivalence to the partial offering equilibrium where $\tilde{a} = o$.

realization. By paying a cost $a \cdot k$, the investor can “inspect” a states to the left of this starting point (that is, she inspects the interval $[y - a, y]$). If a is large enough such that $y - a < l$, she discovers the payoff interval (and consequently has complete information on the asset). We also allow for information acquisition to be sequential. The investor can first decide to discover information about some states, and following this decide whether to analyze more states (and so on).

The modification in the information technology does not alter the investor’s selling decision at $t = 1.3$. She will offer the asset if she is impatient; otherwise she will offer the asset only if she has negative private information about its payoff. The price of the securitized asset, however, will no longer be governed by beliefs about a deterministic amount of information acquisition – the extent of information acquisition is stochastic. We denote the price by \tilde{p} to indicate its dependence on the markets’ beliefs.

We now analyze the investor’s incentives to acquire information at $t = 1$. For this she takes as given a price \tilde{p} at which she can sell at $t = 1.3$. We assume that information acquisition takes place such that the investor decides to acquire information about small intervals of length b (> 0) (we later consider the limit of b tending to zero).

First note that once the investor has discovered the payoff interval, she will not acquire any further information as she already has complete information about the securitized asset. Consider therefore the decision of an investor to acquire information about an interval b given that she has already acquired an amount $a \geq 0$ of information and has not yet discovered the payoff interval.

Multiple cases arise, which are illustrated in Figure 3: First, if $o - a - b \leq l$, the investor knows that the payoff interval will be discovered for sure when more information is acquired. The discovery will benefit her when the realized state of nature s falls in the interval $[l, o - a]$, which occurs with probability $\frac{o-a-l}{n}$. In this case she will be able (if patient) to sell at price \tilde{p} , rather than holding onto a worthless asset. Her expected gains are thus

$$u(l, \tilde{o}) - u(a, \tilde{o}) = \frac{o - a - l}{n} \pi \tilde{p} - bk, \quad (16)$$

which is similar to the equation (3) in the baseline model - except that she now discovers an interval of size $\frac{o-a-l}{n}$. Information acquisition is hence beneficial precisely when $\frac{o-a-l}{n} \pi \tilde{p} > bk$. We can define the option value of information acquisition in this case as $\max\{\frac{o-a-l}{n} \pi \tilde{p} - bk, 0\}$.

Second, we have the case of $o - a - b > l$. In this case it is uncertain whether the

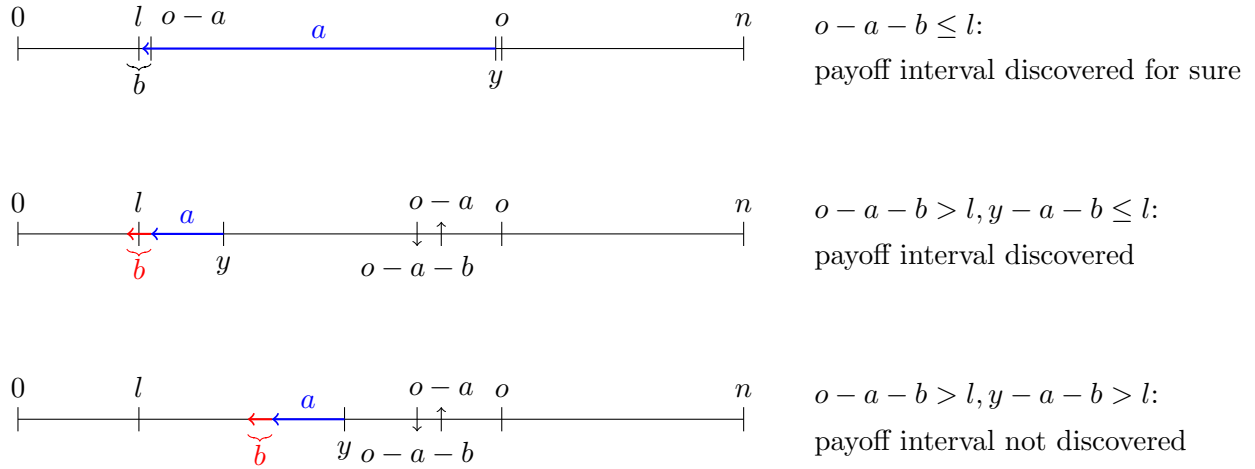


Figure 3: Random Discovery Process

next information acquisition will discover the payoff interval. This will depend on the prior realization of Y . While the realization y is unknown to the investor, she infers from not having discovered the payoff interval yet that $y \in [l + a, o]$. Recall that the investor profits from acquiring information whenever she is patient (with probability π) and the realized state of the world falls in the set of states which the information acquisition has ruled out as potential payoff states. In that case, she obtains \tilde{p} (from selling) instead of zero (from holding on to the asset). When acquiring information about b states, it is certain that at least b states are ruled out, thus implying an expected gain of $\frac{b}{n}\pi\tilde{p}$ (where $\frac{b}{n}$ is the probability that such a state b is realized). Furthermore, she discovers the payoff interval and eliminates uncertainty whenever $y \in [l + a, l + a + b]$. This occurs with probability $\frac{b}{o-a-l}$. If she discovers the payoff interval, she rules out $o - a - l$ states, i.e. $o - a - l - b$ additional states compared to b . The total expected gains from acquiring information when $o - a - b > l$ can therefore be expressed as

$$u(a+b, \tilde{o}) - u(a, \tilde{o}) = \frac{b}{n}\pi\tilde{p} + \frac{b}{o-a-l} \frac{o-l-a-b}{n} \pi\tilde{p} - bk + \left(1 - \frac{b}{o-a-l}\right) V(a+b), \quad (17)$$

where $V(a + b)$ is the option value from acquiring further information in case the payoff interval has not been discovered.

Following this analysis, the value of information acquisition can be recursively defined as

$$V(a) = \begin{cases} \max\{\frac{b}{n}\pi\tilde{p} + \frac{b}{o-a-l}\frac{o-l-a-b}{n}\pi\tilde{p} - bk + (1 - \frac{b}{o-a-l})V(a+b), 0\} & \text{if } a < o-l-b \\ \max\{\frac{o-a-l}{n}\pi\tilde{p} - bk, 0\} & \text{if } a \in [o-l-b, o-l) \\ 0 & \text{if } a \geq o-l \end{cases} . \quad (18)$$

Note that $f(a) := \frac{b}{n}\pi\tilde{p} + \frac{b}{o-a-l}\frac{o-l-a-b}{n}\pi\tilde{p} - bk$ is decreasing in a . This implies that the value of acquiring information about an interval of size b (ignoring the option value of further information acquisition) is declining in the amount of information already acquired. The reasoning for this is as follows: While the likelihood of discovering the payoff interval ($\frac{b}{o-a-l}$) is increasing in a , the expected gains from discovery are decreasing because the number of states which is ruled out (and hence the probability $\frac{o-l-a-b}{n}$ that such a state s is realized) is decreasing in a . It turns out that the latter effect dominates, rendering information acquisition less desirable the more information has already been acquired.

It follows that $f(a) \leq 0$ implies $f(a+b) < 0$. In addition, we can conclude that when $a \in [o-l-b, o-l)$ (that is, when the next information acquisition discovers the payoff interval with certainty) that $f(a-b) > \frac{o-a-l}{n}\pi\tilde{p} - bk$. From this it follows that whenever $f(a) \leq 0$, the option value of information acquisition beyond the next interval is zero ($V(a+b) = 0$). Thus, $V(a) = 0$ whenever $f(a) \leq 0$. It follows that an investor will acquire information as long as $f(a) > 0$, and will stop when $f(a) \leq 0$ or when the payoff interval is discovered.

We first characterize the interior equilibrium. Such an equilibrium is defined by a threshold $a^* \in (0, o-l)$ such that $f(a^*) \leq 0$, but $f(a^* - b) > 0$. For this we consider arbitrarily small intervals of information acquisition. Letting $b \rightarrow 0$, we find that $f(a) = 0$ precisely when

$$\tilde{p} = 2\frac{kn}{\pi} \quad (19)$$

This condition is almost identical to the condition for an interior equilibrium in the baseline model ($\tilde{p} = \frac{kn}{\pi}$). The difference arises because information acquisition is now more valuable since it can lead to the discovery of the payoff interval (while in the baseline model, it only allowed to rule out failure states). Note in addition that (as in the baseline model) this condition does not directly depend on a , but only indirectly through the price. The condition hence pins down an equilibrium path of information acquisition via the condition that the price \tilde{p} is equal to the conditional expected value of the asset when offered.

We next derive this condition. Recall that the investor's strategy can be summarized by a threshold value a^* and let us denote the market's belief about this threshold with \tilde{a} . Note that even though information discovery is stochastic, it only has two possible end results: either the investor finds the payoff interval or she reaches \tilde{a} . Given that the starting point y is distributed on $[l, o]$, the probability of the payoff interval being discovered is simply

$$\pi_0 = \frac{\tilde{a}}{o-l}. \quad (20)$$

The investor will offer the securitized asset if either she is impatient or if she is patient and has negative private information about the asset. The probability of the latter is $\frac{o-l}{o}$ in case she has discovered the payoff interval and $\frac{\tilde{a}}{o}$ in case she has not discovered the payoff interval. The total probability of offering is thus

$$\pi \left(\pi_0 \frac{o-l}{o} + (1-\pi_0) \frac{\tilde{a}}{o} \right) + (1-\pi). \quad (21)$$

An offered securitized asset only has a positive expected value if the investor is impatient (probability $(1-\pi)$), in which case the expected value to the market is $\frac{l}{o}$. We can hence use (20) and (21) to express the expected value of the securitized asset conditional on being offered (and hence its price) as

$$p(\tilde{a}, o) = \frac{(1-\pi)\frac{l}{o}}{\pi \left(\pi_0 \frac{o-l}{o} + (1-\pi_0) \frac{\tilde{a}}{o} \right) + (1-\pi)} = \frac{(1-\pi)l}{(1-\pi)o + \pi\tilde{a}(2 - \frac{\tilde{a}}{o-l})}. \quad (22)$$

In equilibrium we have $\tilde{a} = a^*$ and since the equilibrium is interior additionally $f(a^*) = 0$ (condition (19)). Combining (19) and (22) to eliminate $p(\tilde{a}, o)$, and solving for a^* yields:

$$a^* = (o-l) - \sqrt{(o-l) \left((o-l) - (1-\pi) \left(\frac{2l}{kn} - \frac{o}{\pi} \right) \right)}, \quad (23)$$

where we require $\frac{2l}{kn} > \frac{o}{\pi}$ and $(o-l) > (1-\pi) \left(\frac{2l}{kn} - \frac{o}{\pi} \right)$ to obtain an interior solution $a^* \in (0, o-l)$. Differentiating with respect to o gives

$$\frac{\partial a^*}{\partial o} = 1 - \frac{(o-l) \left(2 - \frac{1-\pi}{\pi} \right) - (1-\pi) \left(\frac{2l}{kn} - \frac{o}{\pi} \right)}{2\sqrt{(o-l) \left((o-l) - (1-\pi) \left(\frac{2l}{kn} - \frac{o}{\pi} \right) \right)}}. \quad (24)$$

This expression is negative since the numerator of the fraction is larger than the denominator. Hence, at an interior equilibrium, information acquisition is declining in opacity o (as in the baseline model).

The cases of no and full information acquisition equilibria are straightforward to analyze. No information acquisition results if at $a = 0$ we have $f(a) \leq 0$. Noting that $a^* = 0$ implies $p = \frac{l}{o}$, we can obtain a critical threshold opacity of $\bar{o} = 2\frac{l\pi}{kn}$, such that opacity levels $o \geq \bar{o}$, deter information acquisition. In contrast, full information acquisition arises when $f(o-l) \geq 0$ (as $b \rightarrow 0$, we can ignore the case of $a \in [o-l, o-l+b]$). (22) yields for $a^* = o-l$ that $p = \frac{(1-\pi)l}{o-\pi l}$. Combining with $f(o-l) = 0$ and rearranging gives a critical threshold $\underline{o} = \pi l + \frac{(1-\pi)\pi l}{2kn}$. For $o \leq \underline{o}$ we hence have a full information acquisition equilibrium.

We can summarize

Proposition 4 *The equilibrium threshold for information acquisition $a^*(o)$ is given by*

$$a^*(o) = \begin{cases} 0 & \text{if } o \geq \bar{o} \\ (o-l) - \sqrt{(o-l) \left((o-l) - (1-\pi) \left(\frac{2l}{kn} - \frac{o}{\pi} \right) \right)} & \text{if } o \in (\underline{o}, \bar{o}) \\ o-l & \text{if } o \leq \underline{o} \end{cases} \quad (25)$$

with $\underline{o} = \pi l + \frac{(1-\pi)\pi l}{2kn}$ and $\bar{o} = 2\frac{l\pi}{kn}$.

We next analyze welfare. In the case of no information and full information acquisition the calculations exactly mirror the baseline model. In the case of an interior equilibrium, however, there is a difference since information acquisition is no longer deterministic. In this case, welfare has to be written as:

$$W(o, a^*(o)) = \frac{l}{n} - k_o \cdot (n-o) - kE[\hat{a}(o)], \quad (26)$$

as welfare losses depend now on the expected information costs $E[\hat{a}(o)]$. It is easy to see that the expected number of times information acquired, $E[\hat{a}(o)]$, is increasing in the cutoff value a^* of an interior equilibrium. It follows that at any o for which an interior equilibrium for information acquisition obtains, welfare is increasing in opacity. Thus, also the interior equilibrium has the same welfare properties as in the baseline model.

A.3 Increasing Cost of Information Acquisition

To analyze increasing costs of information acquisition, let costs be given by a function $k(a) = k(a)$ with $k(0) = 0$, $k'(a) > 0$, $k''(a) \geq 0$ (non-decreasing marginal costs).

Differentiating $u(a, \tilde{a})$ (equation 2) with respect to a then yields

$$\frac{\partial u(a, \tilde{a})}{\partial a} = k'(a) - \frac{\pi}{n} p(\tilde{a}, o). \quad (27)$$

This gives an equation which pins down \bar{o} : $k'(0) - \frac{\pi}{n}p(0, o) = k'(0) - \frac{\pi}{n}\frac{l}{o} = 0$. This term is strictly increasing in o . Thus, since $k' > 0$, there still exist a unique \bar{o} above which no information is acquired. Likewise, \underline{o} is uniquely pinned down by the condition: $k'(o-l) - \frac{\pi}{n}p(o-l, o) = k'(o-l) - \frac{\pi}{n}\frac{1-\pi}{1-\pi\frac{l}{o}}\frac{l}{o} = 0$. Finally, we can write down the condition for the interior equilibrium: $k'(a^*) - \frac{\pi}{n}p(a^*, o) = k'(a^*) - \frac{\pi(1-\pi)l}{n(o-\pi(o-a^*))} = 0$. Totally differentiating with respect to a and rearranging gives

$$a^{*'}(o) = -\frac{(1-\pi)k'(a^*)}{\pi k'(a^*) + k''(a^*)}. \quad (28)$$

Since $k'(a^*) > 0$ and $k''(a^*) \geq 0$, this expression is unambiguously negative. Thus, at an interior equilibrium, opacity reduces information acquisition ($a^{*'}(o) < 0$).

The optimal choice of o for the owner again trades off the information acquisition costs of the investor with the costs of opacity reduction to the bank. As before, the owner's optimization problem is identical to maximizing welfare, which follows equation (8) and is given by

$$W(o, a^*(o)) = \frac{l}{n} - k(a^*(o)) - k_O \cdot (n - o). \quad (29)$$

Differentiating (29) with respect to o

$$\frac{\partial W(o, a^*(o))}{\partial o} = -k'^*(o) \cdot \frac{\partial a^*(o)}{\partial o} + k_O. \quad (30)$$

The opacity choice can now be determined similar to the baseline model: If $n \geq \bar{o}$, $o^* = n$ because then $k(a^*) = k(0) = 0$ and $k_O \cdot (n - o) = k_O \cdot 0 = 0$. If this is not possible due to $n < \bar{o}$, any interior $o \in [\underline{o}, n)$ is dominated by $o = n$. In that region, welfare is increasing in opacity (the expression in (30) is positive because $\frac{\partial a^*(o)}{\partial o}$ is negative by (28) and $k'(a) > 0$).

However, for the region $o \in [l, \underline{o}]$, it no longer is necessarily the case that $o = l$ is the optimal choice (as opposed to the baseline). In particular, because $a^*(o) = o - l$ for $o \leq \underline{o}$, $\frac{\partial a^*(o)}{\partial o} > 0$ and $\frac{\partial^2 a^*(o)}{\partial o^2} = 0$ for that region. This gives

$$\frac{\partial \left(k'^*(o) \cdot \frac{\partial a^*(o)}{\partial o} \right)}{\partial o} = \underbrace{k''^*(o)}_{\geq 0} \cdot \underbrace{\left(a^{*'}(o) \right)^2}_{\geq 0} + \underbrace{k'^*(o)}_{\geq 0} \cdot \underbrace{a''(o)}_{=0} \geq 0.$$

As such, there are two cases: If $k'^*(\underline{o}) \cdot \frac{\partial a^*(\underline{o})}{\partial o} \leq k_O$, the optimal choice of $o \in [l, \underline{o}]$ is $o = \underline{o}$. It is cheaper to let the investor acquire information than to reduce opacity any

further than \underline{o} . However, $o = \underline{o}$ is dominated by $o = n$.

On the other hand, if $k'^*(\underline{o}) \cdot \frac{\partial a^*(\underline{o})}{\partial o} > k_O$, $k'(0) = 0$ ensures that there exists $\tilde{o} \in [l, \underline{o}]$ such that $k'^*(\tilde{o}) \cdot \frac{\partial a^*(\tilde{o})}{\partial o} = k_O$. As such, the opacity choice of the owner can be determined as follows: If $k'^*(\underline{o}) \cdot \frac{\partial a^*(\underline{o})}{\partial o} \leq k_O$, $o^* = n$. If $k'^*(\underline{o}) \cdot \frac{\partial a^*(\underline{o})}{\partial o} > k_O$, the owner has to compare the welfare at $o = \tilde{o}$ and $o = n$ to determine which is better.

A similar result obtains whenever $k(\cdot)$ does not depend on a , but on $(a, n - o)$, with $k(0, 0) = 0$, $\frac{\partial k(a, n-o)}{\partial a} > 0$, $\frac{\partial k(a, n-o)}{\partial (n-o)} > 0$, $\frac{\partial^2 k(a, n-o)}{\partial a^2} > 0$, $\frac{\partial^2 k(a, n-o)}{\partial (n-o)^2} > 0$, $\frac{\partial^2 k(a, n-o)}{\partial a \partial (n-o)} > 0$. In this setup, information acquisition costs are increasing both in the amount of information already acquired and in the number of states that have previously been ruled out by the owner. This captures the idea that the owner first rules out the “cheap” states and thus makes it more expensive for the investor to acquire information. The analysis of the optimal level of information acquisition is as above for a fixed level of o (and thus $n - o$). However, in case of the opacity choice of the owner, the derivation is significantly more complex. This is mainly because the effect of increases in o on a^* are ambiguous: On the one hand, increases in o make it less attractive for the investor to acquire information. This has been documented both in the baseline case and for increasing costs of information acquisition. However, there also is a level effect: Increasing opacity decreases $n - o$ and thus the costs of acquiring information to the investor. It is thus possible that a^* is in fact increasing in o .

To see the implications of this additional effect, consider the following: Suppose that at $o = n$, the investor would acquire a positive amount of information. If the per-state costs of opacity reduction k_O to the owner are sufficiently small, it may pay to set $o = n - \epsilon$ instead of $o = n$. In particular, this is the case if the decrease in opacity deters information acquisition by increasing the marginal costs to the investor. For low k_O , the cost of opacity reduction may be smaller than the gain by deterring wasteful information acquisition.

A.4 Discovering Loss States

Assume now that the securitized asset pays off if nature selects a state $[l, n]$ and zero otherwise. Also assume that information acquisition allows the investor to narrow down the set of loss states. In particular, if she acquires information such that private opacity is $o - a$, she knows that the loss states are distributed on the interval $[0, o - a]$.

For given beliefs about private information acquisition, \tilde{a} , the action of the investors in the trading stage are as follows. When $s \geq o$, both investor and market know that the securitized asset will pay for sure. Its price will hence be 1 and an impatient investor will sell the securitized asset, while a patient investor will not sell given the assumptions we made about the investor's actions whenever indifferent. When $s \in [o - a, o]$, the investor knows that the securitized asset will pay off for sure but the market only has imperfect knowledge about the payoff. The investor has thus positive private information about the asset. In case she is patient, she will hence not sell. If impatient, the investor will still sell. Finally, when $s \in [0, o - a]$, the investor has negative private information. She will thus sell regardless of whether she is patient or not (the expected value of the securitized asset is then $\frac{o-a-l}{o-a}$). The market price of the securitized asset (conditional on $s < o$) is hence

$$p(\tilde{a}, o) = \frac{\frac{a}{o}(1 - \pi) + \frac{o-a}{o} \frac{o-a-l}{o-a}}{\frac{a}{o}(1 - \pi) + \frac{o-a}{o}} = \frac{(o - o - \tilde{a})(1 - \pi) + (o - \tilde{a} - l)}{(o - \tilde{a})(1 - \pi) + o - \tilde{a}}. \quad (31)$$

For $o - \tilde{a} = o \Leftrightarrow \tilde{a} = 0$, this simplifies to $p = \frac{o-l}{o}$, which is the expected value of the securitized asset conditional on a realization $s < o$.

Similar to equation (2) we can derive the investor's utility given market beliefs \tilde{a} :

$$u(a, \tilde{a}) = \frac{n - o}{n} + \frac{o}{n} \left(\frac{a}{o} (\pi + (1 - \pi)p(\tilde{a}, o) + \frac{o - a}{o} p(\tilde{a}, o)) \right) - k \cdot a. \quad (32)$$

The derivative with respect to a is

$$\frac{\partial u(a, \tilde{a})}{\partial a} = \frac{\pi}{n} (1 - p(\tilde{a}, o)) - k. \quad (33)$$

It is useful to contrast this with the marginal benefit of information acquisition in the baseline model ($\frac{\partial u(a, \tilde{a})}{\partial a} = \frac{\pi}{n} p(\tilde{a}, o) - k$). The difference in the first term arises for the following reason: Information acquisition provides the investor with information about the payoff characteristics in additional states. In the baseline model, she learns that the asset will *not* pay in these states. A patient investor thus sells the asset if an analyzed state materializes; she thus benefits from a higher asset price. In the extension considered here, the investor learns that the asset *will* pay off. She thus does not sell the asset if such a state materializes, and her gains hence decline in the market price (which she would otherwise obtain).

The consequence is that for $a = \tilde{a}$, the marginal gains from information acquisition are now increasing in the amount of information acquired (because more information acquisition

means a lower price). This can be seen by evaluating the derivative at $a = \tilde{a}$

$$\left. \frac{\partial u(a, \tilde{a})}{\partial a} \right|_{a=\tilde{a}} = \frac{\pi}{n} (1 - p(\tilde{o}, o)) - k = \frac{\pi}{n} \left(1 - \frac{\tilde{a}(1 - \pi) + (o - \tilde{a} - l)}{\tilde{a}(1 - \pi) + o - \tilde{a}} \right) - k,$$

and noting that this expression is increasing in $a = \tilde{a}$.

The following cases arise: Consider first that $\left. \frac{\partial u(a, \tilde{a})}{\partial a} \right|_{a=\tilde{a}} > 0$ at $a = 0$. This implies that at a conjectured equilibrium with no information acquisition, the marginal gains from information acquisition are positive. Since we know that $\left. \frac{\partial u(a, \tilde{a})}{\partial a} \right|_{a=\tilde{a}}$ is increasing in a , the marginal gains from information acquisition are hence also positive for any $a > 0$. The unique equilibrium is $a^* = o - l$ (full information acquisition). Consider next that $\left. \frac{\partial u(a, \tilde{a})}{\partial a} \right|_{a=\tilde{a}} < 0$ at $a = 0$. In this case, the gains from information acquisition at an equilibrium with no information acquisition are negative. Hence, no information acquisition is an equilibrium ($a^* = 0$). Since $\left. \frac{\partial u(a, \tilde{a})}{\partial a} \right|_{a=\tilde{a}}$ is increasing in a , there might also be other equilibria with more information acquisition. However, we rule out such equilibria by requiring equilibria not to be pareto-dominated.

From solving $\left. \frac{\partial u(a, \tilde{a})}{\partial a} \right|_{a=\tilde{a}} = 0$ for a we obtain the threshold where the switch between no and full information acquisition occurs: $\bar{o} = \frac{\pi}{nk}l$. For $o \geq \bar{o}$ there is then no information acquisition, while for $o < \bar{o}$ there is full information acquisition.

A.5 Different Utility for the Impatient Investor

Suppose that the impatient investor has utility

$$U^{I,I} = C_0^{I,I} + qC_1^{I,I}, \text{ where } q > 1. \quad (34)$$

This change in the setup does not affect the trading stage, but will impact the investor's utility at the information acquisition stage. Similar to equation (2), utility is now

$$u(a, \tilde{a}) = \frac{o}{n} \left(((1 - \pi)q + \pi \frac{a}{o}) p(\tilde{a}, o) + \pi \frac{o - a}{o} \frac{l}{o - a} \right) - k \cdot a. \quad (35)$$

The derivative with respect to a is still $\frac{\pi}{n} p(\tilde{o}^I, o) - k$ – the same as in the baseline model (equation (3)). Allowing for a different utility for an impatient investor thus does not alter the incentives to acquire information. The reason is that information acquisition only benefits the investor if she turns out to be impatient (a patient investor sells regardless of private information). Information acquisition is hence still characterized by Proposition 1.

Welfare is now given by

$$W(o, a^*(o)) = \frac{l}{n} \left[\pi + (1 - \pi)(q - 1) \frac{1 - \pi}{1 - \pi \frac{o - a^*(o)}{o}} \right] - k_o \cdot (n - o) - k \cdot a^*(o). \quad (36)$$

We can see that on top of the effects in the baseline model, opacity has an additional effect because it affects the term $\frac{o - a^*(o)}{o}$, which is an (inverse) measure of the extent of information acquisition. For equilibria with no information acquisition we have $\frac{o - a^*(o)}{o} = 1$, and opacity has no additional effects. For interior equilibria we have that $\frac{o - a^*(o)}{o} = \frac{\frac{o}{\pi} - \frac{(1 - \pi)l}{kn}}{o} = \frac{1}{\pi} - \frac{(1 - \pi)l}{kno}$, showing that increasing opacity has an additional (beneficial) effect on welfare by reducing relative information acquisition.