Rational Opacity

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We present an environment where long term investors sometimes choose to restrict how much fundamental information they receive about the value of their investment to preserve its liquidity in secondary markets. When and only when there is a risk that secondary markets may be shallow, more information can reduce the expected payoff of agents who need to cash out early. Even given direct and costless control over information design, stakeholders choose to incentivize managers to withhold interim information. In such an environment, imposing transparency can lower investment and welfare. (*JEL* G14, D82, D61)

We present an environment where long term investors sometimes choose to restrict how much fundamental information they receive about the value of their investment. This stands in contrast to the traditional view that attributes the lack of communication between investors and managers to agency problems. Under that view, managers have information that would be valuable to stakeholders but it is too costly to set up incentives for managers to share this information.[1] In

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[1] See for instance Milgrom and Roberts (1988) for a review of the traditional literature on agency costs, information, and compensation contracts. They present a canonical model where "[...] it is always optimal for the firm to adjust its promotion criteria and information collection rules from what would otherwise be optimal." Along related lines, the cheap-talk literature started by Crawford and Sobel (1982) shows that when there is any misalignment of preferences between an informed expert and a principal, all Bayesian-perfect equilibria feature some information loss. Even if the principal can write incentive contracts, full revelation is generally suboptimal. Implementing direct revelation, even when feasible, requires the provision of incentives whose cost can outweigh the benefits. See Krishna and Morgan (2008) for a review of these ideas.

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our model, investors have full control over the design of the information policy and yet they choose to be kept in the dark to preserve the liquidity of their investment in secondary markets. Investors choose to introduce agency frictions between themselves and managers to restrict their access to information.

We develop our argument in a simple model of liquidity needs in the spirit of Diamond and Dybvig (1983) and Jacklin (1987). Agents can invest in a long-term project but face the risk that they may need to consume at an interim stage, before the project matures. When they need to liquidate their investment early, they can either scrap the project or, instead, sell it to more patient agents as in Jacklin (1987). Our model differs in several key aspects from the canonical Jacklin framework. First, our agents are risk neutral. Second, the long-term project is risky and its probability of success – its *quality* – is drawn at the interim stage. Third, when they make the original investment, agents can design how much information they would like to receive on the project quality at the interim stage. Information is free so that agents can choose at no cost full public information, no information at all, or anything in between these two extremes.

The optimal information design becomes more opaque, in a sense we make precise, as the risk of early liquidation rises. While more information allows investors to scrap early when ex-post efficient, it can also reduce the expected payoff when agents are constrained to liquidate their investments. Investors may be forced to liquidate at a price that does not reflect the fundamental value of the project when secondary markets are shallow. Therefore, cash-in-the-market pricing in the sense of Allen and Gale (2005) imposes an upper bound on the investment's liquidation value in some states, thus making our risk neutral investors effectively risk averse. Coarser information provides some insurance to those early investors who have to liquidate their project.

Given this logic, it would seem that the optimal situation for investors would be to observe project quality privately at the interim stage in order to make efficient scrapping decisions without incurring the risk of liquidation losses. That intuition turns out to be correct from an individual point of view, but wrong in equilibrium. As in Milgrom and Stokey (1982) all private information is revealed when projects trade in secondary markets. As a result, private information can hurt investors if they cannot commit to restrict it. It is optimal, therefore, for investors to restrict their access to information in some fashion.

One natural way to implement the desired solution is for investors to delegate the project continuation decision to a manager. The manager's compensation scheme should induce him to reveal the desired level of information. We show that the compensation scheme that implements the constrained optimal scrapping policy features a participation in revenues when the project matures and a severance payment if the manager chooses to scrap it early. In other words, the natural implementation of the optimal contract in our environment involves imposing a veil between investors and investment managers.

Doing so, we draw a connection between the literature on the optimal level of information pioneered by Hirshleifer (1971, 1972) and the cash-in-the-market pricing literature introduced by Allen and Gale (1994). Allen and Gale analyze how the depth of secondary markets may affect asset price volatility. We focus instead on the consequences of cash-in-the-market pricing on the optimal control of the fundamental information investors receive. Hirshleifer (1971, 1972) shows that interim information can make agents worse off by introducing "redistributive risk" or by lowering the market value of long-term projects. In our model, original investors recognize this "Hirshleifer effect" and, rationally, choose the level of information that maximizes their ex-ante welfare. Like us and in the context of interbank loans, Goldstein and Leitner (2015) relate optimal information disclosure to a possible Hirshleifer effect.

A link between information and "short-termism" is also present in, e.g. Bolton, Santos, and Scheinkman (2011), Zetlin-Jones (2013), or Von Thadden (1995), but we consider the optimal design of the information structure rather than taking it as given. Our implementation of the desired solution via delegation is reminiscent of Aghion, Bolton, and Tirole (2004) but we design a mechanism that induces the manager to keep most information to themselves rather than a contract that encourages the revelation of information.

Our paper is also related to the banking literature where banks are seen as especially opaque.[2] The closest paper to ours in the banking area is Dang, Gorton, Holmstrom, and Ordonez (forthcoming) and we discuss it at length in Section 7.3.[3]

In different contexts, Kaplan (2006), Goldstein and Sapra (2014), and Bouvard, Chaigneau, and de Motta (2015) link information disclosure to bank runs or other forms of roll-over risks.[4] More recently Andolfatto, Berentsen, and Waller (2014) show that the threat of undue diligence – the possibility that agents may decide to acquire private information – can influence the socially optimal disclosure policy. In Diamond (1984)

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[2] See Morgan (2002) and Flannery, Kwan, and Nimalendram (2004, 2013).

[3] See also Gorton and Pennacchi (1990), Breton (2007), Dang, Gorton, Holmstrom, and Ordonez (forthcoming) and Siegert (2012).

[4] Goldstein and Sapra (2014) survey the literature on the cost and benefits of disclosing stress test results and they conclude that full disclosure is rarely desirable. For the literature on disclosure regulation see Leuz and Wysocki (2008) and the references therein. In particular, Kurlat and Veldkamp (2013) argue that information disclosure can reduce investors' payoffs as it decreases asset return.

and Diamond (1985) opacity is a result of agency problems arising from costly information acquisition.

Pagano and Volpin (2012) and Monnet and Quintin (forthcoming) also argue that limiting the disclosure of fundamental information can be optimal but for vastly different reasons from those we articulate in this paper. Partial opacity in those models encourages the participation of lay investors which can be strictly welfare enhancing when acquiring expertise is costly.

On the technical side, the information design problem we solve is similar to the Bayesian persuasion game studied by Kamenica and Gentzkow (2011). One difference between our environment and Kamenica and Gentzkow's is that our senders – the early investors at date 0 – know that they will receive the message at date 1 but that secondary market investors will receive it as well. The fact that our setting contains multiple receivers turns out to be inconsequential however since all receivers interpret the message in the same way.

1. The environment

We begin by describing an environment where liquidity-minded investors have the opportunity to invest in a long-term risky project.

1.1 Investment opportunities and preferences

Consider an economy with three dates $t=0,1,2$, and unit measures of two types of agents. The first type of agents are early investors who are endowed with one unit of a consumption good at $t=0$. The second type are late investors who appear at date $t=1$ with an endowment $A>0$.

As will soon become clear, the size of the endowment of late investors pins down the size of secondary markets in our model. Therefore, we will think of A as capturing the expected depth of secondary markets when early investor select their information disclosure policy. When A is low, secondary markets are shallow, and, as we will argue below, assets are more likely ex ante to sell at a price that is below their expected payoff, as in Allen and Gale (2005). Our main result will be that this leads early investors to opt for a more opaque information policy. One simplifying assumption is that A is deterministic. This shortens several of the upcoming arguments but dealing with the stochastic case does not present major technical difficulties or change the nature of our results, as we explain in the online Appendix.

A fraction $\pi\in[0,1]$ of early investors and a fraction $1-\pi$ of late investors want to consume at date 1 while other agents want to consume at date 2. As a result, half of all agents consume at date 1, while the other half want to consume at date 2.[5] We will refer to π as the liquidity risk for early investors. As of date 0, early investors do not yet know whether they will want to consume early or late hence they seek to maximize:

$$u(c_1,c_2;\pi) \equiv \pi c_1 + (1-\pi)c_2, \tag{1}$$

where c_1 is their expected consumption in period $t=1$ conditional on being an early consumer while c_2 is expected consumption at $t=2$ conditional on being a late consumer.[6]

Agents have the option to store the consumption good across dates. The economy also comprises a risky project that, if continued at full scale until date 2, yields either $R>1$ or nothing. Activating the project requires an aggregate investment of one unit of the consumption good at date 0. In particular, all early investors must commit their endowment to the risky project in order to activate it. When they do so, early investors receive an equal claim to the project's output.

As of date 0, early investors know that the success probability $q \in [0,1]$ will be drawn at date 1 from a distribution F with a continuous and strictly positive density in $[0,1]$. At date 1, any investor can scrap their portion of the project for a payoff $S>0$ which is independent of q. When fraction $\kappa \in [0,1]$ of the project is scrapped at date 1, the total project payoff at date 2 is $(1-\kappa)R$ when the project is successful, zero otherwise. The scrapping decision captures the option to interrupt, downsize or re-purpose long-term investment projects in which cases S is the value of the next best use of the invested capital, net of re-purposing costs.[7]

Parameters could in principle be such that early investors are always better off storing their endowment but we focus on the more interesting case where early investors choose to invest in the risky project. Specifically, we assume throughout that

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[5] This symmetric assumption on the risk of early consumption for early and late investors simplifies notation in the upcoming analysis by implying that a mass π of agents want to liquidate their projects a date 1 (namely early investors who turn out to be early consumers) and the same mass of agents are willing to buy projects at date 1 (namely late investors who turn out to be late consumers.) Even though this pins down the number of potential buyers in secondary markets, we can still vary the depth of secondary markets at will by varying A. Doing so, in fact, gives us one of the main comparative statics we establish in this paper, see Corollary 1.

[6] We assume here that a law of large number holds: π is both the fraction of early investors who turn out to be early consumers and the likelihood that a particular early investor will become an early consumer.

[7] As we will explain, it turns out in this environment that if it is optimal for one primary investor to scrap their share of the project, it is optimal for all investors to do so, so that either the entire project is scrapped or it is continued at full scale. Be that as it may, the specification of scrapping options we use embeds a constant return-to-scale assumption. One could imagine that scrapping by some investors diminishes the returns of remaining investors. This would only increase incentives by remaining investors to scrap as well, which would reinforce the prediction that either the entire project is scrapped or it is continued at full scale.

$$1 < \pi \min\left(A, \int qRdF\right) + (1-\pi)\int qRdF. \quad (2)$$

As will become clear below, (2) implies that early investors choose to invest in the risky project even when they have no information about project quality. Of course and as we will discuss at length in this paper, early investors can typically do better by releasing some information about project quality at date 1.

Also to shorten the exposition we will assume throughout that $A > S$. This will imply that there are always enough resources in secondary markets to pay at least the scrapping value of the project. In addition, only one price clears the Walrasian market for project shares that we now describe.[8]

1.2 Secondary market

At date 1, agents can buy or sell claims to the risky project's output in a Walrasian market. Agents take the equilibrium share price as given. They buy or sell shares to maximize their expected utility given the information they have.

In the online Appendix we show that our model with Walrasian trade makes the exact same predictions as a model where early investors who wish to consume early are matched with exactly one late investor who wish to consume late and the former gets to make the latter a take-it-or-leave it offer. The transaction we model in the secondary market is also isomorphic to a secured debt contract between early and late investors that gives early investors the share price $p(m(q))$ at date 1 in exchange for a payment of R contingent on the project being successful.[9]

While both the option to scrap and the option to sell project shares in secondary markets enable early investors to get an early payoff, they are very different in nature. Scrapping a share of the project eliminates the possibility of a project payment at date 2. One should think of it as a redeployment of the capital invested in the risky project to a different use and more information allows investors to exercise that option more efficiently. In contrast, secondary markets enable investors to sell claims to date 2 payoffs. More information does not raise the ex-ante value of that option but it can lower it as we will show. The value of the scrapping option could depend on new information about q but we assume for simplicity and without loss of generality for our purposes that it is independent of q.

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[8] When $A < S$, the scrapping option dominates what secondary markets can offer regardless of what information is available at date 1. Secondary markets are irrelevant, therefore, and full information is always best for original investors.

[9] See the online Appendix.

1.3 Information

This paper is principally about what early investors choose to know about q once it is drawn at date 1. To learn about q, early investors can choose to activate an information technology at date 0. This technology sends a message m once q is realized at date 1. Early investors are free to choose any message function in the following set:

$$\{m:[0,1]\mapsto\mathcal{B}([0,1]):q\in m(q) \text{ for almost all } q\in[0,1]\}$$

where $\mathcal{B}([0,1])$ is the space of Borel subsets of $[0,1]$. Restricting the choice of message functions to satisfy $q\in m(q)$ is without loss of generality[10] and has the advantage that the technology can be thought of as announcing a subset of $[0,1]$ to which q belongs. In Section 4, we will discuss the option for early investors to keep information to themselves and argue that this does not affect any of our results. Finally, restricting our attention to deterministic message functions is also without loss of generality as we will show when we fully characterize the optimal information design choice of early investors.[11]

Agents are free to become fully informed about the project quality by setting $m(q)=\{q\}$ for all $q\in[0,1]$. One of our main results, however, is that early investors usually opt for much coarser information technology designs, unless they know they will consume late, that is unless $\pi=0$. Choosing no information − $m(q)=[0,1]$ for all $q\in[0,1]$ − is always an option as well, but is not optimal either unless $\pi=1$.

1.4 Equilibrium

At date 0, early investors establish a message function and decide whether or not to commit their endowments to the risky project.[12] At the start of date 1, late investors appear, all consumption types are revealed, and a message $m\in\mathcal{B}([0,1])$ becomes available. Agents immediately and correctly translate this message into an expected likelihood of success for the long-term project,

$$E(q|m)=\frac{\int_m q\,dF}{\int_m dF}. \tag{3}$$

[10] To see why this is without loss of generality take any Borel-measurable mapping h from $[0,1]$ to an arbitrary message space. Then the set-valued mapping $m:[0,1]\mapsto\mathcal{B}([0,1])$ defined for all $q\in[0,1]$ by $m(q)=h^{-1}\circ h(q)$ has the desired properties and conveys exactly the same information as h. In other words, as long as all agents understand the selected design of the information technology, they can invert any message into a subset of $[0,1]$.

[11] See the proof of Proposition 2.

[12] Suppose instead that early investors first receive the information and then decide whether or not to activate the project. The nature of our results would continue to hold since the decision not to activate the project is then akin to the decision to scrap it in the set-up we study.

Given those expectations, we show in the next section that a unique price clears the Walrasian market for shares at date 1. Given this price, early agents decide, first, whether to scrap their share of the project.[13] Agents who do not scrap their project shares decide whether to buy and sell their claim to output at date 2. At date 2, all agents consume the proceeds from their claims to the risky project or their storage investments.

In this context, an equilibrium is a decision by early investors whether or not to activate the risky project, a message function, and, for each possible message at date 1, a share price, scrapping decisions, share trading decisions by early and late investors, and consumption plans, such that:

1. Given the message function, all agent decisions at date 1 are optimal and the Walrasian market for shares clears for every possible message;
2. No other message function and associated Walrasian price schedule gives early investors a higher expected payoff as of date 0.

In the online Appendix we show that the allocation that obtains in this equilibrium is the one that a social planner who seeks to maximize the welfare of early investors would select, as long as the planner must abide by minimal participation constraints and cannot preclude early and late investors from entering into side-trades at date $t=1$. In particular, the equilibrium we characterize is constrained-efficient.[14]

2. Market for project shares

Given $\pi \in [0,1]$ and $A>0$, let $p(m(q))$ be the price of a project share when the message $m(q)$ is issued at the start of period 1. To keep notation simple we do not make explicit the dependence of market prices on the model's parameters. If $E(q|m(q))R \leq S$ then secondary market buyers are willing to pay no more than S per project share and no early investors is willing to accept less since they could always scrap their share of the project. In that case, it must be that $p(m(q))=S$ for markets to clear.

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[13] The next section shows that that there is no disagreement on this decision between early and late consumers. In fact, in all equilibria, either the entire project is scrapped or it is continued at its original scale.

[14] Because by assumption we assume that the message function is the same for all investors – all investors receive the same information at date 1 – they agree to select the design that maximizes their common welfare ex-ante. One could alternatively assume that each investor chooses a message function independently, making room potentially for non-symmetric equilibria. As long as messages are public and messages function must be set before investors discover their date 1 type, it is at least weakly optimal for each agent to select the message policy we describe in this paper. But if at least one investor selects that solution, other investors need no longer select it as well, so that non-symmetric optimal solutions also exist. In all cases, the equilibrium allocation and the optimal shape of public information would still be the one we describe in this paper.

Assume, on the other hand, that $E(q|m(q))R > S$. If $p(m(q)) > E(q|m(q))R$ then all early investors sell but no late investors are willing to buy since they are better off storing their endowment. So we must have $p(m(q)) \leq E(q|m(q))R$. If the inequality is strict only early consumers may sell (π shares are supplied at the most). Late investors for their part, consume their endowment if they turn out to be early consumers at date 1. Those who are late consumers spend all their endowment on projects if $p(m(q)) < E(q|m(q))R$ making demand $\frac{\pi A}{p(m(q))}$ which is consistent with market clearing only if $p(m(q)) = A$ which, in turn, is consistent with the premise that $p(m(q)) < E(q|m(q))R$ only if $A < E(q|m(q))R$. When $A \geq E(q|m(q))R$ the same argument leads to $p(m(q)) = E(q|m(q))R$ as the only market clearing price. In summary,

Proposition 1. Given a message function m, at the Walrasian stage and for almost all $q \in [0,1]$,

$$p(m(q)) = \max[S, \min\{E(q|m(q))R, A\}]. \tag{4}$$

All proofs are in the appendix. The argument is illustrated in Figure 1. Given the message, the share price must fall between S and the expected payoff $E(q|m(q))R$. As long as the price is the expected payoff, late investors who want to consume late are willing to spend their entire endowment on project shares making demand (the dashed line) the entire interval between 0 and $\frac{\pi A}{p} = \frac{\pi A}{E(q|m(q))R}$. To move beyond that demand level, the price must fall and demand becomes $\frac{\pi A}{p}$ for $p \in (0, E(q|m(q)R)$. Supply (the solid line) is $[0,\pi]$ when $p = S$, is exactly π when $p \in (S, E(q|m(q))R)$ and becomes $[\pi, 1]$ when $p = E(q|m(q))R$ since in that case even late consumers are willing to sell their share.

The figure shows the case where there are not enough resources to purchase all the shares at fair value, that is when

$$\frac{\pi A}{E(q|m(q))R} < \pi \Longleftrightarrow E(q|m(q))R > A. \tag{5}$$

Then the only equilibrium price is $p(m(q)) = A$. In other words, the price is dictated by the resources available in the market rather than the project's expected payoff. This is a situation Allen and Gale (2005) describe as cash-in-the-market pricing. On the other hand, if $\frac{\pi A}{E(q|m(q))R} \geq \pi$, then the equilibrium price is the expected payoff. We will show that cash-in-the-market pricing implies a trade-off between information and liquidity.

One simple consequence of this result is that Walrasian prices always exceed the proceeds early investors receive when the project is scrapped. This implies that there is no conflict of interest between patient and impatient investors when it comes to the continuing decision. If patient

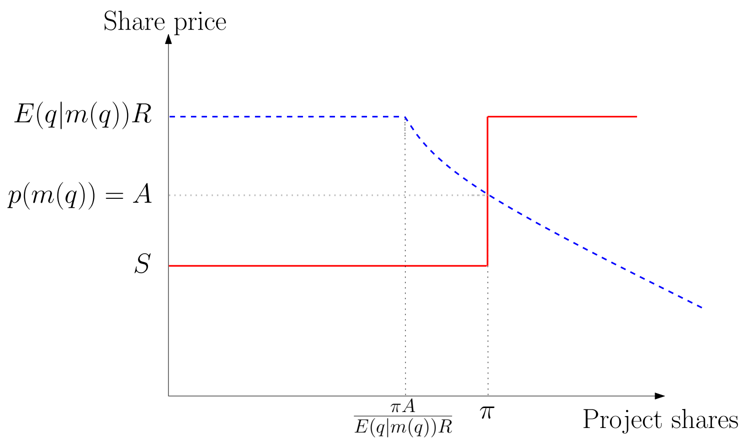

Figure 1
Walrasian market for project shares under cash-in-the-market pricing

investors wish to continue the project at full scale, impatient investors are at least as well off agreeing with this decision as they would be if the project is scrapped. In any equilibrium then, either the project is scrapped in full with all investors agreeing with this decision or it is continued at full scale.

We assume that A is fixed but q varies while Allen and Gale (2005) assume the reverse. We need q to vary to create an interesting information problem. The key aspect of both environments, however, is that projects may sell at a discount when A is small relative to q. We keep A fixed for simplicity but making both q and A stochastic is easy and does not alter any of our results, as we show in the online Appendix.

3. Rational Opacity

We are now in a position to characterize the information design decisions of early investors. It will be instructive to first consider a parametric example where the trade-off between information and liquidity is transparent. We will then characterize the general solution to our information problem.

3.1 An illustrative example

Assume that technological parameters are such that

$$A < \int qRdF. \tag{6}$$

In this particular part of the parameter space, there is cash-in-the-market pricing in secondary markets when no information is provided as

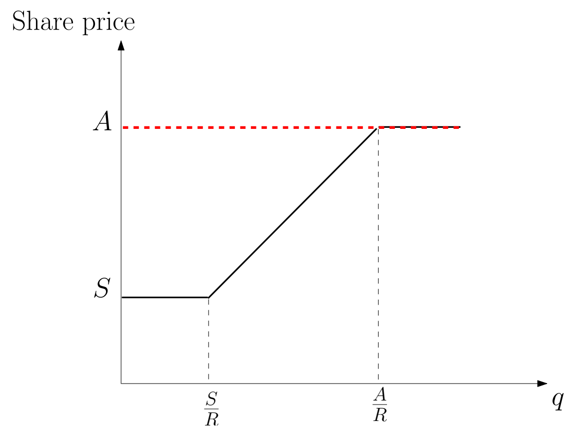

Figure 2
Price under full information (solid) and no information (dashed).

the share price cannot be above A, as we explained above. In this case, the fact that $A > S$ implies that information reduces the sellers' expected payoff from secondary markets since late investors are already willing to pay A when no information is provided. In other words, the Walrasian price is as shown in Figure 2 for the two polar information cases: The solid line shows the price with full information and the dashed line shows the price with no information. In this specific case, information cannot have any positive effect on liquidation value but when the news is bad, if q is low, it can have a negative effect on secondary market prices.

To make clear the resulting trade-off between information and liquidity, observe that if early investors opt for no information, their ex-ante payoff is

$$\pi A + (1-\pi)\int_0^1 qRdF. \tag{7}$$

Indeed, they can sell their share of the project for A in secondary markets when they must consume early and, if they turn out to be late consumers then they keep their shares to maturity, as no new information becomes available at date 1. If on the other hand early investors opt for full information, their expected payoff is

$$\pi\left(\int_0^{\frac{S}{R}} SdF + \int_{\frac{S}{R}}^{\frac{A}{R}} qRdF + \int_{\frac{A}{R}}^1 AdF\right) + (1-\pi)\left(\int_0^{\frac{S}{R}} SdF + \int_{\frac{S}{R}}^1 qRdF\right). \tag{8}$$

Information is valuable ex-post for late consumers because it enables them to make efficient scrapping decisions, thus obtaining a higher expected payoff,

$$\int_0^{\frac{S}{R}} SdF + \int_{\frac{S}{R}}^1 qRdF > \int qRdF, \tag{9}$$

but it is costly for early consumers because it reduces the expected liquidation value of project shares at date 1:

$$\int_0^{\frac{S}{R}} SdF + \int_{\frac{S}{R}}^{\frac{A}{R}} qRdF + \int_{\frac{A}{R}}^1 AdF < A. \tag{10}$$

A trivial consequence of these observations is that given only a choice between full information and no information, early investors would only opt for full information if their liquidity risk is low enough.

We can say much more. Assume that agents can design the message function in any way they wish. Revealing information cannot improve early investors' payoff if they must consume early, as condition (6) implies that their payoff is already at its maximum if they do not receive any information. The only point of revealing some information, then, is to make better scrapping decisions. It follows that there is no need for the message function to partition [0,1] in more than two subsets: scrap or hold. While late consumers would like to be informed when $qR < S$, there is no value in having more information than just $q \geq \frac{S}{R}$. To summarize, while the value of marginal information in $[\frac{S}{R},1]$ is non-negative, revealing that information could reduce early investors' payoff when they have to consume early.[15]

These simple observations give us the first source of opacity. It is not rational for early investors to reveal any information beyond what is strictly necessary to induce efficient scrapping decisions. Late investors, for their part, would value finer information, but they have no means to induce the original investors to provide it.

We will show in full generality below that the two subsets, scrap and hold, are non-overlapping intervals.[16] We can thus restrict our search for optimal message functions to the following class of functions, indexed by $\bar{q} \in [0,1]$: for $q \in [0,1]$,

$$m(q) = \begin{cases} [0,\bar{q}] & \text{if } q < \bar{q} \\ (\bar{q},1] & \text{otherwise.} \end{cases} \tag{11}$$

At date zero then, early investors need only choose $\bar{q}$. We refer to $\bar{q}$ as the scrapping threshold. An obvious possibility is to set $\bar{q} = \frac{S}{R}$

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[15] A formal proof of this claim as well as other claims we make in this intuitive discussion are provided in the next section where we take on the optimal design problem in full generality.

[16] Our arguments in this respect are similar to those of Kamenica and Gentzkow (2011). See the proof of Proposition 2 for details.

which would enable late consumers to always make the ex-post efficient scrapping choice. In this case, the message is designed to convey the most information subject to the constraints we have outlined above. This design, however, turns out to be optimal only when $\pi=0$ and early investors know they will consume late.

To characterize the optimal design, notice that the early investors' payoff is

$$V(\bar{q}) \equiv \pi\left(\int_0^{\bar{q}} SdF + \int_{\bar{q}}^1 AdF\right) + (1-\pi)\left(\int_0^{\bar{q}} SdF + \int_{\bar{q}}^1 qRdF\right). \quad (12)$$

Since V is continuous on a compact set, an optimal $\bar{q}$ exists for all $\pi\in[0,1]$. While the payoff function is not necessarily concave in the scrapping threshold for arbitrary density functions, it is hill-shaped with a single peak so that the optimal threshold is in fact unique. Furthermore, V is strictly submodular on $\left[0,\frac{S}{R}\right]$: the early investor's marginal payoff is decreasing in π. Therefore, the higher the liquidity risk, the greater the cost of increasing the scrapping threshold. Intuitively, there is a trade-off between the desire to scrap when it is efficient to do so and the fact that better information can lower the project's resale value. This implies that investors who face a relatively low liquidity risk will choose a higher scrapping threshold. And, inversely, investors facing a high liquidity risk will prefer a lower scrapping threshold and possibly no information at all.

In this simple parametric case, one can show[17] that the optimal scrapping cut-off is

$$\bar{q} = \max\left\{\frac{S-\pi A}{(1-\pi)R}, 0\right\}. \quad (13)$$

Indeed, we argue below that if the optimal scrapping solution is interior it must satisfy the following first order condition:

$$\pi A + (1-\pi)\bar{q}R = S. \quad (14)$$

Any $q>\bar{q}$ such that the left hand side of the equality exceeds the right-hand side should be included in the holding message, as holding then dominates scrapping. Of course, consistency requires that the holding

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[17] For a concrete example, assume that F is uniform. Then

$$V(\bar{q}) \equiv \bar{q}S + \pi(1-\bar{q})A + \frac{(1-\pi)R}{2}\left(1-\bar{q}^2\right).$$

This function is strictly concave in $\bar{q}$ and its derivative vanishes at $\frac{S-\pi A}{(1-\pi)R}$.

strategy be optimal for late consumers given the message. But (6) guarantees that they are willing to hold on to their shares if no new information is revealed, so they remain willing to do so upon learning the good news that $q \geq \bar{q}$. For the same reason, since late investors are willing to pay A before hearing that $q \geq \bar{q}$, this remains true after learning the good news.

This result implies in particular that the optimal $\bar{q}$ is zero on $(\frac{S}{A},1]$ and decreases strictly on $[0,\frac{S}{A}]$. More liquidity-minded (high π) early investors thus opt to reveal less information. It also suggests that deeper secondary markets – a higher A – causes early investors to opt for more opacity. But, as will now see, this only holds in the particular part of the parameter space on which this section focuses. The relationship between the depth of secondary markets and opacity turns out to be more complicated than this simple example would suggest. To see this, we now turn to the general solution of the information design problem.

3.2 The general solution

This section provides the general solution to our problem. Intuitively and as discussed in the example above, a trade-off only exists between liquidity and information when project shares sell at a price below their expected value. Otherwise, it is never optimal to withhold information. Capturing this idea is the main direction in which we need to generalize the example. To shorten the exposition, we will proceed assuming that $\pi \in (0,1)$.[18]

The previous example assumed that $A < \int qRdF$ which holds when A is low. When $A \geq \int qRdF$ lowering the scrapping threshold would eventually mean that projects sell at their expected value in the holding region, so that cash-in-the-market pricing no longer holds, hence there is no remaining reason to withhold information. Therefore, in the general case, a key quality cutoff is the threshold $\tilde{q}(A)$ past which, if the message $q \geq \tilde{q}(A)$ is emitted at date 1, projects sell at price A, below their expected value. This threshold is defined by

$$\tilde{q}(A) = \max\left\{\tilde{q} \in [0,\frac{S}{R}] : E(qR|q \geq \tilde{q}) \leq A\right\} \tag{15}$$

with the understanding that $\tilde{q}(A) = 0$ if $E(qR) > A$. Original investors have no incentive to shrink the scrapping message beyond that threshold. Formally,

[18] When $\pi = 0$ the secondary market can play no role and early investors opt for full information. If $\pi = 1$, information has no value and choosing no information is always optimal.

Proposition 2. The optimal information design consists of a scrapping message and a holding message. The scrapping message is $F-$essentially an interval $[0,\bar{q}(\pi,A)]$ where

$$\bar{q}(\pi,A)=\max\left\{\frac{S-\pi A}{(1-\pi)R},\tilde{q}(A)\right\}. \tag{16}$$

The proof provided in the appendix consists of several steps. First we show that we can restrict the search for the optimal message function to binary functions – scrap or hold – and that these functions are two non-overlapping intervals with no gaps. This implies the existence of a scrapping threshold $\bar{q}$ such that agents receive the scrapping message whenever $\bar{q}<q$ and the holding message otherwise. Second, we show that $\bar{q}\geq\tilde{q}(A)$. Otherwise, and given (15), raising $\bar{q}$ would strictly raise the early investors' expected payoff. Therefore their problem is to maximize their expected payoff subject to $\bar{q}\geq\tilde{q}(A)$, which yields (16). Finally, we show that random messages would not help early investors in achieving a higher expected payoff.

Cash-in-the-market pricing – the possibility that market price may depend on available resources on the demand side for projects – plays a critical role in our results. It introduces a cap on prices hence on the early consumer's payoff, thus making their payoff function non-linear in $m(q)$. As a consequence, even though agents are risk neutral, liquidity concerns can make them behave as if they were risk-averse.

3.3 Key implications

This general result has several immediate consequences. First, it yields the main comparative statics results we seek to establish in this paper.

Corollary 1. At the optimal information design:

1. $\bar{q}(\pi,A)$ decreases weakly with π, strictly so if and only if $\bar{q}(\pi,A)\in(\tilde{q}(A),\frac{S}{R})$.
2. $\bar{q}(\pi,A)$ is U-shaped in A. Given $\pi\in[0,1]$, there exists $\bar{A}(\pi)\leq\int_{\frac{S}{R}}^{1}qRdF$ such that $\bar{q}(\pi)=\frac{S}{R}$ if $A\geq\bar{A}(\pi)$, and the optimal scrapping thresholds first decreases and then increases on $[S,\bar{A}(\pi)]$.

The first item states that more liquidity-concerned investors choose a lower scrapping threshold. A testable version of this prediction is that organizations whose stakeholders value liquidity highly should be especially opaque. This is the converse of the main point made by Zetlin-Jones (2013). The negative relationship between the liquidity risk and information revelation comes from the basic trade-off between liquidity and information we discussed earlier. The second item says that the trade-off is only operative when the market price of projects is affected by the endowment of late investors. It should be clear that scrapping low quality projects is always optimal when $A \leq S$. Hence, in this case $\bar{q}(\pi,A) = \frac{S}{R}$. At the opposite end, when A is so large that shares always sell at their expected payoff, information cannot affect liquidation value and there is no need to take the risk of holding the project when it would be efficient to scrap, so that again $\bar{q}(\pi,A) = \frac{S}{R}$. In between these two thresholds, there is cash-in-the-market pricing in secondary markets and the scrapping threshold does depend on A.

Notice that a lower threshold $\bar{q}(\pi,A)$ is an increase in opacity: as the threshold decreases, the set of project quality for which all investors receive the same information is larger. Put another way, original investors become more prone to curtail the release of bad news. One testable version of this prediction is that investments for which secondary market opportunities are ample should feature few if any curbs to the release of interim information about fundamentals.

One direct way to test this prediction is to study the relationship between the size of secondary markets for a particular project and proxies for transparency.[19] More indirectly, opacity should be more prevalent in industries where barriers to entry into secondary markets – legal restriction or the cost of learning about complex investment projects, for instance – are high. As should be clear and as Section 5.2 will formalize, industries with high entry costs are more likely to feature cash-in-the-market pricing. Another indirect way to test this basic prediction of our model is that opacity should be especially prevalent when secondary markets are in their infancy as they tend to be for new industries.

The risk of shallow secondary markets, in our world, is a necessary condition for opacity to serve a purpose. But Corollary 1 also says that the relationship between the expected depth of secondary markets is not globally monotonic. To make this stark, if secondary markets do not exist, full information is obviously optimal. As secondary markets grow from insignificant and start becoming relevant opacity initially worsens but eventually falls. In other words, our model produces a Kuznets-curve-like relationship between secondary market development and transparency.

More fundamentally, Proposition 2 also implies that equilibria can be inefficient. In cases where $\bar{q}(\pi,A) < \frac{S}{R}$, early investors choose a scrapping threshold that induces them to keep the project in some states of the world when they should not. Therefore, total expected output is strictly below what would prevail under full information as is, therefore,

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[19] Morgan (2002) and Flannery, Kwan, and Nimalendram (2004, 2013) propose various ways to proxy for the opacity of corporations.

aggregate expected consumption. The inefficiency arises from the fact that ignorance is bliss for those agents who must sell their project. In summary:

Corollary 2. The equilibrium allocation under rational information design can be Pareto inefficient.

Finally, an important result is that while information distortions may lower expected output below its potential, this does not imply that imposing transparency necessarily causes output to rise. In fact, yet another consequence of proposition 2 is that doing so may lead to a decrease in expected output.

Corollary 3. Imposing full information can lead early investors to opt for storage rather than the risky project. In particular, it can cause expected output and expected consumption to fall.

As in Andolfatto, Berentsen, and Waller (2014) therefore, more transparency can imply less investment and hence destroys total surplus. Here, this occurs because imposing full information lead liquidity-minded investors to opt for less productive projects with safer short-term returns. Our result is also reminiscent of Goldstein and Sapra (2014) who argue that disclosing too much information on stress test results could trigger runs and destroy value. Von Thadden (1995) also presents a model where the possibility of asymmetric interim information between investors and firms can cause the optimal contract to feature "short-termism" in the sense that short-term investments are preferred to more productive investments. The mechanism behind this aspect of our model is quite different however: stakeholders are concerned about their ability to liquidate their investment at a good price and transparency, therefore, can reduce the value of entering into long-term investment projects.

4. Private information

So far we have assumed that if information is made available to some agents, then it is public information. Our results seem to suggest that early investors would prefer to observe project quality privately at date 1 to make efficient scrapping decisions without incurring the risk of liquidation losses. This section shows that this intuition is wrong. While it is true that each investor has an incentive to be better informed than other agents, this is true for all agents, and general equilibrium arguments imply that acquiring private information can only hurt investors. Since they are unable to commit not to act on their private information, their willingness to trade in secondary markets will make public any private information. Therefore private information can only hurt investors if they cannot commit to restrict it. One solution to this paradox is to delegate the reception of information to a representative investor with the right incentives.

4.1 Trade reveals all private information

Assume that early investors always observe the interim signal perfectly but privately. In that case, as long as late investors observe the supply of project shares, the Walrasian market reveals all private information which means that the equilibrium allocation is the same as in the full information case.

Remark 1. If early investors observe project quality privately then the only equilibrium allocation is the full information equilibrium allocation.

This observation should not come as a surprise: agents' willingness to trade at the interim stage reveals all private information in this environment as in Milgrom and Stokey (1982).

Since unbridled access to private information can lead to an inferior allocation from the ex-ante point of view of early investors, they have an incentive to observably commit to remaining ignorant. To explore this possibility, assume now that agents can make the *design* of private information they select observable to late investors, or, equivalently, that they can somehow commit to it. In this case, late investors observe what information design early investors selected. At the trading stage, late investors can infer all information early investors received from their willingness to trade shares and, therefore, the equilibrium is the same as when the signal is public.

Remark 2. If the design of the information technology is observable, the rational information design choice is the same regardless of whether the message is private or public.

Put another way, all the results we established in the previous section go through unaffected when information is private rather than public. In addition, this section says that investors who must confront liquidity risk have incentives to observably commit to reveal any information they have (say, via delegated monitoring) or to not trade on the basis of that information (say via regulations that ban trading on the basis of undisclosed information.)

4.2 Implementation via delegation

The analysis above suggests that agents have an incentive to find ways to commit to ignore – or at least not to act upon – their private information. In this section we show that a natural way to implement the desired solution is to delegate the project continuation decision to a risk-neutral representative agent (e.g. a manager, operating entity or General Partner) with the right incentives. Assume then that the coalition of early investors hire an agent with no holdings in the project and give her the authority to scrap the project at date 1. Assume further that only this agent is given full access to the signal at date $t=1$.

Consider the class of compensation scheme whereby the manager receives a fixed payment $M>0$ if the project is scrapped – think of it as a severance payment – and, if the project is continued, receives a payment αR if the projects succeeds– think of this part of her compensation as a participation in revenues. For simplicity, we assume that the manager has no mass so that, in particular, the payment she receives does not affect the expected surplus generated by the project. We now have:

Proposition 3. Let $\bar{q}(\pi)$ be the optimal scrapping threshold given $\pi\in[0,1]$. Let the manager's compensation scheme (M,α) be such that

$$M=\alpha\bar{q}(\pi)R. \tag{17}$$

Then the manager implements the optimal scrapping policy and, correspondingly, early investors expect the constrained-efficient payoff.

Investors can implement the ex-ante optimal allocation and information design by creating ex-post conflict of interests between a manager and at least some of the stakeholders. Late consumers would prefer upon discovering their type that all information be revealed. By committing to delegation with a carefully designed set of incentives, stakeholders are committing to the ex-ante optimal information environment. Far from being a friction that ought to be addressed as it is in traditional models, agency costs serve to implement the constrained optimal solution.

Note that the proposition does not pin down the level of the compensation scheme so that in principle, the entire one-dimensional space of schemes that satisfies the desired property implement the optimal policy. Since the manager has no mass, investors are indifferent across such schemes as long as they involve finite payments. In the online Appendix we introduce moral hazard and we show that – among other insights – doing so provides a natural way to pin down the level of the optimal compensation scheme.

5. Extensions

This section considers two important variations on the model we have used to establish our main results: a version of the model with a continuous operating choice variable, and a version where the depth of secondary markets is endogenous.[20]

5.1 Continuous project control variable

The coarse nature of the optimal information design that obtains in the model we have used so far is not simply a consequence of the assumption that the only meaningful decision that takes place at date 1 is whether to scrap or hold. In fact, we could get rid of the scraping decision altogether and we would still find that some opacity is optimal when there is a risk that secondary markets may be shallow. To see this, generalize our model by assuming that at date 1 and after project quality q has been drawn the expected project payoff is $qR(y,q)$ where y is a continuous control variable and R is a function that rises continuously with q for all y. We assume that the choice of control at date 1 cannot be hidden from late investors. So more information is better because knowing q allows to choose the optimal y.[21]

We write $y(m)=\text{argmax}_y E[qR(y,q)\,|\,q\in m]$ for the action that maximizes the expected payoff of a holder of the project if investors receive some message m in period 1. Notice that $qR(y(\{q\}),q)\geq qR(y(m),q)$ for any q whenever $q\in m$, so that investors always prefer to have full information.

We assume there is cash in the market pricing. That is we define $\tilde{q}$ as the solution to

$$E[qR(y([\tilde{q},1]);q)\,|\,q\geq\tilde{q}]=A, \tag{18}$$

so that whenever investors receive message $[q,1]$ where $q>\tilde{q}$ then the project will sell for A and we further assume that $\tilde{q}<1$.

This modeling change should affect the optimal design of information since knowing q now matters not only for continuation decisions but also for optimal operation choices. It turns out the optimal information design now reveals full information at the bottom and at the top of the quality interval, while giving no information in the middle, in a way the following proposition makes precise.

Proposition 4. Suppose $\pi<1$. Then there is $q_0>\tilde{q}$ and $q_1\in(q_0,1]$ such that the optimal message structure is $m(q)=q$ for all $q\in[0,q_0)\cup(q_1,1]$ and $m(q)=[q_0,q_1)$ for all $q\in[q_0,q_1)$. Furthermore,

$$E[qR(y([q_0,q_1]);q)\,|\,q\in[q_0,q_1]]=A. \tag{19}$$

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[20] The online Appendix contains a version of the model with stochastic secondary market depth and a version in which early investors make strictly interior storage choices.

[21] For instance, one could specify

$$R(y,q)=q^{1-\alpha}y^{\alpha}-yw$$

where $w>0$ is a unit cost and $\alpha\in(0,1)$. One could then think of y as labor input or as capacity utilization in the sense of Greenwood, Hercowitz, and Huffman (1988).

When $\pi = 1$, $q_0 = \tilde{q}$ and $q_1 = 1$.

As before, the region where there is no information is a consequence of cash-in-the-market pricing, and the region becomes larger as the probability to consume early increases. The intuition is simple. Information is useful as it allows to choose the optimal control y. When investors know they want to consume early ($\pi = 1$), they do not care about information details for high quality projects as they know they will not operate the project. So they choose to bundle high quality projects with as many low quality projects as possible, and our previous information structure obtains. When $\pi < 1$ however early investors trade-off liquidity and optimal control. For q large, full information is optimal because they know the project would sell for A if they want to consume early, while they can choose the optimal control variable when they turn late consumers. For q low, investors know the project sells for S as it should be scrapped and full information is also (weakly) optimal there. For middle range quality, investors trade-off liquidity and optimal control just like in the benchmark version of our model, and the range depends on the probability to consume early. The higher the probability the larger the range.

In turn, the same delegation approach with the appropriate compensation scheme implements the optimal allocation. Optimal delegation of control thus implements the optimal solution even when continuous decisions are present. The bottom line is that introducing continuous control variables attenuates but does not eliminate incentives by investors to control information flows.

5.2 Endogenous market depth

So far we have treated market depth as independent of information design. However, in the model, opacity impacts the rents secondary market buyers generate which creates a feedback effect from opacity to market depth. To make this clear, this subsection embeds our one-project model into a broader framework where the size of secondary markets is endogenous.

Consider an economy that contains a unit interval of locations each containing one investment project and a unit mass of early investors both exactly as described in section 1. The economy also contains an unbounded mass of late investors who appear at date 1 each endowed with exactly one unit of the consumption good. Those late investors can choose to store their endowment. They can also choose to join one location which enables them to participate in Walrasian markets for project shares in that location when they open at date 1. For concreteness we assume that the decision to join a particular market takes place before any information is revealed at date 1.[22] This simplifies the analysis by making the size of secondary markets independent of the message issued although, of course, that size depends on the information design selected by primary investors.

Joining a location is potentially costly however and we denote by $c_i \geq 0$ the cost associated with joining location $i \in [0,1]$. For simplicity but without loss of generality, we take this cost to be a utility cost so that late investors who enter a location all have their unit of endowment available for purchasing project shares. We interpret this cost as capturing the time and resources necessary to locate a particular market and learn its characteristics.

A general equilibrium in this context is a location decision for each late investor – allowing for the possibility that a given investor participates in no market – and, at each location, an information design choice by early investors and Walrasian prices for projects at date 1 such that:

1. The information design maximizes the ex-ante payoff of early investors given Walrasian prices at each location;
2. Secondary markets clear at all locations, i.e Walrasian prices are as defined in 1 where A now stands for the mass of late investors in a given location;
3. Net of entry costs, late investors earn the the same payoff (namely 1) as they would if they stored their endowment.

To understand why the third condition must hold, observe that if late investors earned a return net of learning costs that exceed storage returns in some locations, they would keep entering locations with the highest return since they are available in unbounded numbers. Entry must eventually drive all returns net of entry costs down to the storage return. The following results characterizes equilibria in this extension of our basic model.

Proposition 5. An equilibrium exists. Furthermore, all equilibria are such that markets where entry costs are strictly positive and secondary markets are active (i.e. $A_i > 0$) feature cash-in-the-market pricing.

The proof we provide in the appendix formalizes the two-way connection between market depth and opacity. Given a potential size A_i of secondary markets in location i, only one information policy – i..e only one scrapping level $\bar{q}_i(A_i) \leq \frac{S}{R}$ – is optimal. The associated rents for secondary market investors are

$$F(\bar{q}_i(A_i)) + [1 - F(\bar{q}_i(A_i)] \frac{\pi E(q | q \geq \bar{q}_i(A_i))R}{A_i} - 1. \tag{20}$$

[22] We make this assumption for simplicity only. It would still be the case that cash-in-the-market must prevail when entry decisions are made after the date 1 message is issued. The complication is that the size of markets may now depend on the message.

Indeed, if $q < \bar{q}_i(A_i)$ then the project is scrapped and either sold at price S to late investors or the proceeds of scrapping are consumer by all early investors. In that case investors earn no more than they would from storing their endowment. If, on the other hand, the message $q < \bar{q}_i(A_i)$ is issued then the project is continued and late investors expect return $\frac{\pi E(q|q \geq \bar{q}_i(A_i))R}{A_i}$.

Holding A_i constant, a decrease in $\bar{q}_i$ means lower rents for late investors. To see this, remember that continuing the project when $q < \frac{S}{R}$ yields negative returns for project holders. In equilibrium then, more opacity in the sense of a marginal decrease in $\bar{q}_i$ must be associated with smaller secondary markets to preserve secondary market investors' rents. In that sense, this environment with endogenous secondary markets exhibits a feedback effect from opacity to market depth.

The key consequence of introducing endogenous and costly entry is that some measure of cash-in-market pricing hence some opacity must characterize all markets whose entry cost is strictly positive so that gross rents that exactly offset learning costs are generated. Secondary markets that carry learning costs must feature some cash-in-the-market pricing in this environment.

6. Applications

This section briefly describes several possible interpretations of our framework and discusses our model's predictions in each of these contexts.

6.1 Private equity markets

Private equity markets have at least two salient, distinguishing features vis-a-vis their public counterparts. They are illiquid – opportunities to liquidate partnership interests are restricted – and they are opaque – under the typical arrangement, most original investors only receive from fund operators the bare-minimum information needed to compute the distributions to which they are contractually entitled. Our model establishes a clear connection between these two features.[23]

The vast majority of private equity funds are structured as Limited Liability Companies or Limited Partnerships and feature a collection of passive investors (Limited Partners, or LPs) and a designated fund manager (General Partner, GP) who exercises sole control over the fund's operations. In fact, under the Limited Partnership Act, it is only

[23] See Metrick and Yasuda (2010), Kaplan and Stromberg (2009), and Gompers and Lerner (1999) for details about the structure of the private equity markets, including the Limited Liabilities Companies structure or the organization of Venture Capital Funds.

by relinquishing all control to the GP that LPs are guaranteed limited liability protection.[24]

Secondary market options are becoming broader and deeper,[25] and, at the same time, there is some evidence that demand for transparency is on the rise in private equity markets.[26] In part, this is a consequence of the massive losses institutional investors suffered during the recent crisis prompting many of them to ask for at least some experimentation with a new equity fund model. But our model points to another possible explanation for enhanced communication between operators, GPs and LPs. As more and larger investors enter secondary markets, our model suggests that transparency should improve under the optimal contracting arrangement.

The optimal implementation we propose in section 4.2 requires highly contingent agreements between passive investors, managers, and operating entities that provide financial rewards when the investment project performs well and severance payments when the investment project must be shut down early. The most typical incentive scheme for GPs takes the form of a "promote" structure whereby the GPs' share of profits rises when certain internal rate return thresholds are met by LPs, together with claw-back periods when late losses reduce earlier returns. Also Delaware law governing partnership agreements between LPs and GPs provides for the maximum "freedom of contract" and, as a result, the GP's obligations can be defined as narrowly as needed to maintain LPs uninformed. Many partnership agreements merely require the release of cash flow information necessary to the computation of distributions to LPs, and stated or mandatory fiduciary responsibilities of partnership operators usually do not require the release to investors of soft information that operating entities receive over time about the fund's prospects.

Many partnership agreements require that investors get the approval of other partners before selling their interests, which seems potentially inconsistent with our Walrasian market set-up. However, the transaction we model in the secondary market is isomorphic to a contingent debt contract between early and late investors that gives early investors the share price $p(m(q))$ at date 1 in exchange for a payment of R contingent on the project being successful. Under that contract, early investors

[24] See Naidech (2011) for a thorough description of the typical GP-LP setup in the United States.

[25] See https://www.seic.com/docs/IMS/SEI-PE-Liquidity-Challenge_US.pdf. As Galfetti, Perembetov, and Marks (2014) explain, secondary market participants tend to be specialists suggesting that barriers to entry into these markets remain high.

[26] See e.g. http://www.seic.com/docs/IMS/IMS-PE_Whitepaper_US_FINAL.pdf?cmpid=im-pe3-pr-11.

formally keep their partnership interest, receive p at date 1, and a net zero payoff at date 2 whether or not the project succeeds.

6.2 IPO markets

Alternatively, one could think of the secondary markets in our framework as Initial Public Offering (IPO) markets. Under this interpretation, our investors play the role of founders and initial investors who get their first opportunity to cash out their investments in public markets at date 1. The fraction of π of shares can be interpreted as the fraction of initial investors who experience a liquidity shocks. Alternatively, one could assume that all initial investors prefer to cash out their investment at date 1 but that they must abide by lockup constraints.

The fact that disclosure is limited in primary asset markets is discussed by Pagano and Volpin (2012) among many other papers. Pagano and Volpin (2012) and Monnet and Quintin (forthcoming) show that limited disclosure can mitigate the adverse selection issues that result from the coexistence of expert and non-expert markets in those markets. Our model point to a different, complementary motivation for carefully managing the release of fundamental information about assets, namely the fact that the depth of IPO markets is uncertain. As we have argued, when cash-in-the-market pricing is a possibility, it becomes optimal to scramble information and bundle bad news with good news.

In this context, the implementation we propose in section 4.2 is best interpreted as the delegation of marketing decisions to an underwriter who receives a fixed proportion of IPO proceeds $q(\bar{\pi})R$. As discussed for instance by Ljungqvist (2007), the level of disclosure by underwriters varies a lot across IPOs. The literature has also found an empirical correlation between the level of disclosure and the level of underpricing. This finding is broadly consistent with our model in the sense investors who are concerned that their shares may sell at a discount vis-a-vis the value that would prevail when markets are deep opt for more opaque disclosure designs.

Two strong empirical regularities in this context are that underpricing tends to be more severe in IPOs when the ratio of institutional to non-institutional investors is higher and that institutional investors earn higher returns than other investors on their IPO investments (see e.g. Michaely and Shaw 1994, Aggarwal, Prabhala and Puri 2002, and Caseres Field and Lowry 2009.) Section 5.2 contains a potential explanation for these findings. IPOs that require a higher cost to be analyzed or valued say because they involve complex or new types of assets are more likely to be targeted by specialists. Higher participation costs, in turn, imply a higher ratio of institutional to non-institutional investors and higher returns in equilibrium. This simple explanation does not rely on the traditional adverse selection arguments introduced by Rock (1986). Instead, the underpricing implied by endogenous cash-in-the-market constraints simply serves to offset participation costs for secondary market investors.

6.3 Banks

A traditional interpretation of a framework such as ours in the spirit of Diamond and Dybvig (1983) is to think of our set of early investors as forming a bank for the purpose of creating liquid claims backed by illiquid but productive assets. This is the interpretation adopted for instance by Dang, Gorton, Holmstrom, and Ordonez (forthcoming) in an environment that shares several key features with ours.[27] The traditional Diamond and Dybvig bank contract involves storing part of the resources invested at date 0. We rule that solution out by assumption since the project requires all available funds to be activated at date 0. Instead, liquidity is provided by secondary market investors which, in this banking interpretation, could be thought of as agents who invest equity into the bank at date 1.

However, as is well known in this context (see Jacklin 1987) and is especially clear in a model like ours where project shares trade according to a Walrasian protocol, the interpretation of the implicit two-period contract as a banking contract is arbitrary. When trade is possible at date 2, markets suffice to deliver the constrained optimal allocation. Breton (2007) and Dang, Gorton, Holmstrom, and Ordonez (forthcoming) make the case that what makes banks essential is their ability to conceal information. They are "optimally opaque institutions."

Their banks are, in fact, fully opaque. Even though their framework is very similar to ours, they find that full opacity is optimal as opposed to the partial disclosure solution that emanates in our model. The reason for this difference is the fact that our model contains a scrapping option of potentially positive value and that whether this shut-down information is employed at date $t=1$ is public information. If we allowed project managers to hide scrapping decisions, to store scrapping proceeds when they are positive, and compensate the manager with a carefully chosen fraction of proceeds at maturity, then it is easy to show that the manager would scrap when and only when $q \leq \frac{S}{R}$, as needed to maximize surplus. In that environment, secondary markets always pay the no-information price – scrapping decisions, since they are unobserved, have no consequences on liquidation values – exactly as in Dang, Gorton, Holmstrom, and Ordonez (forthcoming). While low-quality projects may have been scrapped, secondary markets buyers only

[27] See also Breton (2007).

discover that they bought bad projects when proceeds are distributed at maturity.

The key assumption we are making, therefore, is that some actions cannot be concealed. The full opacity solution described in the previous paragraph would involve managers selling to date-1 investors projects which they have been shut down or divested and are no longer in operation. In practice, it seems reasonable to think that actions with drastic consequences such as shutting down an entire investment project are difficult to hide. In that case, partial opacity rather than full opacity is typically optimal, as we have demonstrated in this paper.

However, in the banking context, the primary focus of Dang, Gorton, Holmstrom, and Ordonez (forthcoming), the assumption that projects can be shut down unbeknownst to stakeholders seems more reasonable, for two reasons. First, banks' key stakeholders are its diffuse depositor base, each of whom has comparatively little exposure to the performance of each of the bank's long-term investments. Second, banks hold large and complex portfolios of positions making the monitoring of project-specific actions more costly for depositors.

6.4 Cross-border investments

Finally, our framework could help shed some light on the choice between Foreign Portfolio Investment (FPI) and Foreign Direct Investment (FDI) cross-border investors have to make. Our model predicts that if investors care about the option to sell their investment early and markets for these foreign interests are shallow then they should prefer to receive less interim information about the quality of these investments. As discussed by Goldstein and Razin (2006), FDI investors effectively become the managers of the firm they invest in, while FPI investors are more passive since they do not involve any direct control or management of the firm. In the context of out model, FPI is a way for investors to remain less informed about the quality of the firm as they delegate its management to the current investors. To the contrary, FDI makes investors more informed about the firm's prospects.

Our theory implies that the choice of investment strategy should depend on the depth of secondary markets for foreign interests. Specifically, our model implies that we should observe relatively more FPI when foreign markets are shallow and relatively more FDI when they are deep.

This idea is related to Goldstein and Razin (2006) who also explain the choice between FDI and FPI through information. They argue that investors with a strong preference for liquidity may prefer FPI, as it is less susceptible to the lemons problem inherent in FDI (FDI investors may sell because they know their investment is bad). Therefore, FDI investments sell at a discount. As a result investors with strong liquidity needs should prefer FPI over FDI. Our theory suggests another rationale for the choice between FDI and FPI that does not rely on private information ex-post, but on the depth of foreign markets: countries where financial markets are shallow should have relatively more FPI. As pointed out Goldstein and Razin (2006) the fact that more liquidity-minded investors tend to opt for FPI rather than FDI could also explain why FPI flows are significantly more volatile than FDI flows.

7. Conclusion

In this paper we argue that curtailing the flow of interim information about expected payoffs can be a rational choice for long-term investors who are concerned about secondary market depth because of a natural trade-off between information and liquidity. A natural way to restrict their own access to information is to delegate project management to agents whose compensation provides them with incentives that differ from the ex-post incentives of original investors. In our model therefore and far from being a friction that ought to be addressed, agency costs serve to implement the constrained optimal solution. Imposing transparency may lower welfare.

Proofs

Proposition 1

Take any q and associated message $m(q)$. If $p(m(q)) > E(q|m(q))R$ then all early investors would sell their shares at date 1 while there are no buyers. If, on the other hand, $S < p(m(q)) < E(q|m(q))R$ then only early investors who need to consume early sell their projects. In that case, all late investors who need to consume at date 2 buy as many projects as they can afford, namely $\frac{A}{p(m(q)}$ so that demand equals supply if and only if

$$\pi \frac{A}{p(m(q);\pi,A)} = \pi \Longleftrightarrow p(m(q);\pi,A) = A. \qquad \text{(A1)}$$

Finally, if $E(q|m(q))R \leq S$ then the optimal strategy for any project shareholder is to scrap it. Therefore we must have $p(m(q)) = S$ so that all agents are indifferent between buying or selling project shares.

Proposition 2

To ease the exposition in the context of this proof, we will dispense with all "$F-$essentially" qualifiers. Statements we make below about various subsets of project quality levels are understood to apply except possibly on sets of F-measure zero.

We will first characterize the solution under the assumption that the messages must be deterministic but will then argue that this assumption can be dropped without changing the solution. When the message function is deterministic, information takes the form of a partition of the interval (namely the range of the inverse of the message function) and we can assume that for all possible q the message is a subset $m(q)$ of $[0,1]$ that contains q itself.

Consider any solution to the early investors' information design problem (i.e. consider any optimal message function.) Let $\mathcal{H}$ be the union of messages $m \subset [0,1]$ that induce late consumers to hold their shares with probability one, while $\mathcal{S}$ is the complement set, i.e. the union of messages that induce scrapping with strictly positive probability. The expected payoff for early investors given this messaging strategy can be written as:

$$\pi \left\{ F(\mathcal{S})S + \int_{\{q:m(q)\subset\mathcal{H}\}} \min(E(qR|m(q)),A)\,dF \right\} + (1-\pi)\{F(\mathcal{S})S + F(\mathcal{H})E(qR|\mathcal{H})\} \tag{A2}$$

To understand this expression, note that project shares are scrapped with positive probability by late consumers only if $E(qR|m(q)) \leq S$. Given the same message then, secondary markets are willing to pay no more than S for shares, so that the expected payoff is the same whether shares are sold or scrapped by early investors. If the project is continued on the other hand, late consumers get as payoff the expected date 2 revenue. Early consumers get $\min(E(qR|m(q)),A)$ from secondary markets. But note that

$$\begin{aligned} & \textstyle\int_{\{q:m(q)\subset\mathcal{H}\}} \min(E(qR|m(q)),A)\,dF \\ \leq \quad & \min\left(\textstyle\int_{\{q:m(q)\subset\mathcal{H}\}} E(qR|m(q))\,dF, F(\mathcal{H})A\right) \\ = \quad & F(\mathcal{H})\min(E(qR|\mathcal{H}),A) \end{aligned} \tag{A3}$$

so that merging all messages that lead late consumers to hold into one hold message can only raise the expected payoff of early investors. Henceforth then we can restrict our search for the optimal message functions to binary functions: hold or scrap.

Next we show that $\mathcal{S}$ is an interval that contains the origin. If this is not the case then there are two sets M_1 and M_2 of equal and strictly positive F-mass such that the first set is in $\mathcal{H}$, the second set is in $\mathcal{S}$, and $M_1 < M_2$. Moving M_2 to $\mathcal{H}$ and M_1 to $\mathcal{S}$ leaves the scrapping part of the expected payoff unchanged but, since the q's are higher in M_2 than in M_1, this strictly raises the payoff conditional on holding. If follows, then, that we must have $\mathcal{S} = [0,\bar{q}]$ and $\mathcal{H} = (\bar{q},1]$ for some $\bar{q} \in [0,1]$.

Next assume (yet again by way of contradiction) that $\bar{q} < \tilde{q}(A)$ which implies, in particular, that $\bar{q} < \frac{S}{R}$. Then secondary markets pay $E(qR|\mathcal{H})$ when the hold message is issued. Indeed, the definition of $\tilde{q}(A)$ implies that when $\bar{q} < \tilde{q}(A)$, $E(qR|q \geq \bar{q}) < A$ so that shares trade at their expected value in secondary markets when the hold message is issued. It follows that the ex-ante expected payoff for date-0 agents is

$$\int_0^{\bar{q}} S\,dF + \int_{\bar{q}}^1 E(qR|q \geq \bar{q})\,dF. \tag{A4}$$

But since the scrapping threshold is such that $\bar{q} < \frac{S}{R}$ so that $\bar{q}R < S$, raising $\bar{q}$ marginally would strictly increase the payoff, contradicting the premise that the messaging strategy was optimal.

These results, taken together, imply that the optimal scrapping threshold maximizes:

$$\begin{aligned} V(\bar{q};A) \equiv \pi & \left\{ \int_0^{\bar{q}} S\,dF + \int_{\bar{q}}^1 A\,dF \right\} \\ & \left\{ +(1-\pi)\int_0^{\bar{q}} S\,dF + \int_{\bar{q}}^1 qR\,dF \right\} \end{aligned} \tag{A5}$$

subject to:

$$\bar{q} \geq \tilde{q}(A). \tag{A6}$$

The unconstrained maximizer of V is easily seen to be $\max\left\{\frac{S-\pi A}{(1-\pi)R}, 0\right\}$. If the constraint does bind, the solution is $\tilde{q}(A)$ instead.

To complete the proof, we now need to argue that the suggested information design remains optimal even if random messages are allowed. Consider then general message functions h defined from $[0,1]$ to the set of probability distributions on a given message space $\mathcal{M}$ that includes at least the set of all Borel measurable subsets of $[0,1]$ so that, in particular, the optimal deterministic solution remains feasible. We will require that h be such that for any subset $\mathcal{P}$ of $\mathcal{M}$ that has a positive mass in the distribution induced by $F \circ h$, $E(qR|\mathcal{P})$ is well defined. The same Jensen inequality argument as in the deterministic case implies that we may restrict our attention to a binary message space, scrap or hold, and we denote each message as before by $\mathcal{S}$ and $\mathcal{H}$, respectively. The complication is that date-0 agents may now randomize over those two possibilities for a set of $q \in [0,1]$.

Assume, first, that at the optimal messaging policy $E(qR|\mathcal{H}) > A$ but that there is a set of positive mass in $[0, \max\left\{\frac{S-\pi A}{(1-\pi)R}, 0\right\})$ such that the probability that $\mathcal{H}$ is emitted given almost any q in that set is strictly positive. Take a subset of those q's sufficiently small that $E(qR|\mathcal{H}) > A$ continues to hold even if we change the message to scrap for those q's. Since $\pi A + (1-\pi)qR < S$ by construction for those quality levels, the ex-ante payoff for date-0 agents rises strictly when we do make that policy change. This implies that q's in $[0, \max\left\{\frac{S-\pi A}{(1-\pi)R}, 0\right\})$ must trigger the scrap message with probability one as before. The same argument implies that if $E(qR|\mathcal{H}) > A$, q's in $(\max\left\{\frac{S-\pi A}{(1-\pi)R}, 0\right\}, 1]$ trigger the hold message with probability one. If $E(qR|\mathcal{H}) > A$ then, the messaging policy is deterministic.

If $E(qR|\mathcal{H}) < A$ then early investors expect the same payoff regardless of whether they turn out to be early or late consumers. In that case, if the scrapping policy is not the full-information one, the payoff can be strictly raised by changing the message policy as above, without perturbing the fact that $E(qR|\mathcal{H}) < A$, a contradiction. In particular, the message policy is once again deterministic.

Finally, conditional on $E(qR|\mathcal{H}) = A$, it is easy to see that the payoff is at its highest possible level when messages are deterministic and $\bar{q} = \tilde{q}(A)$.

These three scenarios for $E(qR|\mathcal{H})$ cover all possibilities and, in all cases, the message function is deterministic. This completes the proof.

Corollary 1

The first item is obvious. As for the second item, note first that if A is sufficiently high, $\tilde{q}(A) = \frac{S}{R}$, and the optimal threshold is $\frac{S}{R}$. As A falls $\tilde{q}(A)$ falls below $\frac{S}{R}$, the threshold initially traces $\tilde{q}(A)$ an increasing function of A. As A falls further, it starts tracing $\frac{S-\pi A}{(1-\pi)R}$ instead, a decreasing function, until that function becomes exactly $\frac{S}{R}$ which occurs at $A = S$.

Corollary 3

Assume that parameters satisfy:

$$S < \int \max(S, \min(qR, A))dF < 1 < A < \int qRdF. \tag{A7}$$

In other words, the expected payoff from fully informed secondary markets is dominated by the storage payoff, but it continues to be the case that selling to uninformed secondary markets dominates storage. Now consider early investors with a high liquidity risk. If π is high enough, constraining early investors to provide full information will cause them to opt for storage, thus causing a decline in investing activity since those same agents would choose to invest if they could opt for no (or, more generally, less) information.

Proposition 4
To make upcoming arguments easier, we will first show that the optimal message structure is a partition of [0,1] formed of non-overlapping intervals. To that end, we show that the strategic communication results of Crawford and Sobel (1982, CS) apply to our set-up. CS write the sender's and receiver's utility as $U^S(y,m,b)$ and $U^R(y,m)$, respectively, where y is the action taken by the receiver, m is a random variable (our q) and b is a scalar to measure how different the sender and the receiver are from each other. The sender observes his type, m and then has to communicate it to the receiver. In our model, the sender is the early investor in period 0, who devises the message structure. The receiver is the same investor in period 1, when he has to take the action on the scale of the project. That is, we can define

$$U^S(y,q,\pi)=\pi\min\{\max[qR(y,q),S];A\}+(1-\pi)U^R(y,q) \tag{A8}$$

and

$$U^R(y,q)=\max[qR(y,q),S] \tag{A9}$$

Notice that π plays the role of b in CS. One difference is that our sender does not observe q. But this does not matter since he's not the one taking the action y. Notice we have

$$U^S(y,q,\pi)=\pi\min\left\{U^R(y,q);A\right\}+(1-\pi)U^R(y,q) \tag{A10}$$

Given π and q, we assume that there is a unique maximum y for S and R, and we assume a sorting condition $\frac{\partial^2 qR(y,q)}{\partial y\partial q}>0$ so that our payoff functions satisfy the assumptions imposed by CS. They show that the optimal message structure is an interval-partition of [0,1].

Knowing that the optimal message structure is non-overlapping intervals $[0,q_1);[q_1,q_2);..;[q_n,1]$ allows us to use the lower bound of each interval as a sufficient statistics for that interval. We write $\bar{q}_i=[q_i,q_{i+1})$. Therefore, when agents receive message $q\in[q_i,q_{i+1}]$, we can write the optimal investment decision as

$$y(\bar{q}_i)=\arg\max_y E[qR(y;q)\,|\,q\in\bar{q}_i], \tag{A11}$$

Then we write $R(\bar{q}_i,q)=R(y(\bar{q}_i),q)$ so that the expected payoff at the optimal level of input given message $\bar{q}_i$ is

$$E[qR(\bar{q}_i;q)\,|\,q\in\bar{q}_i]. \tag{A12}$$

We begin with a simple observation:

Remark 3. Let $\pi=1$. Then optimally, the message is $m(q)=q$ for all $q<\tilde{q}$ and $m(q)=[\tilde{q},1]$ for all $q\geq\tilde{q}$.

The argument is intuitive: When investors are sure to sell their project, they only care about its scale to the extent that it increases its value. But whenever the message is such that $E[qR(\bar{q}_i;q)\,|\,q\in\bar{q}_i]>A$, investors only sell it for A. So there is no gain in designing such a message. Instead, investors prefer to bundle all project types above $\tilde{q}$ such that $E[qR([\tilde{q},1];q)\,|\,q\in[\tilde{q},1]]=A$. For all $q<\tilde{q}$, full disclosure increases the value of each project as they all sell for $qR(q;q)<A$. We now turn to the case where $\pi<1$.

Lemma 1. Suppose $\pi < 1$. Then optimally, there is $q_0 > \tilde{q}$ and $q_1 \in (q_0, 1]$ such that the message is $m(q) = q$ for all $q < q_0$ or $q \geq q_1$ and $m(q) = [q_0, q_1)$ for all $q \in [q_0, q_1)$. Furthermore,

$$E[qR(\bar{q}_0; q) \,|\, q \in \bar{q}_0] = A. \tag{A13}$$

Proof. That full information is optimal for $q < \tilde{q}$ follows from the fact that the payoff of the sender and receiver coincide in that region. Now we concentrate on q_0 and we show $q_0 \geq \tilde{q}$. First, notice that q_0 is such that $E[qR(\bar{q_0}; q) \,|\, q \in \bar{q}_0] \geq A$. By way of contradiction, suppose q_0 satisfies

$$E[qR(\bar{q}_0; q) \,|\, q \in \bar{q}_0] dF(q) < A \tag{A14}$$

It should be clear that $q_1 R(y(q_1); q_1) > A$ as otherwise, the receiver and sender's payoff would coincide on the interval $[q_0, q_1)$. Hence, $q_0 R(y(q_0); q_0) < A$ and the receiver and sender's payoff coincide in a neighborhood of q_0. Therefore, the message is dominated by $\tilde{m}$ such that $\tilde{m}(q) = q$ for all $q < q_0 + \varepsilon$ and $\tilde{m}(q) = [q_0 + \varepsilon, q_1)$ for all $q \in [q_0 + \varepsilon, q_1)$ and $\tilde{m}(q) = m(q)$ for all $q > q_1$, where ε is chosen such that

$$E\left[qR\left(\overline{q_0 + \varepsilon}; q\right) \,|\, q \in \overline{q_0 + \varepsilon}\right] \leq A. \tag{A15}$$

This contradicts that our original message was optimal. Hence,

$$E[qR(\bar{q}_0; q) \,|\, q \in \bar{q}_0] \geq A. \tag{A16}$$

Above, we showed that $q_1 = 1$ when $\pi = 1$. When $\pi = 0$ however, $q_1 < 1$. Indeed in this case, $m(q) = \{q\}$ is optimal (i.e. $q_1 = q_0$). Hence, by continuity, we necessarily have $q_1 \leq 1$ whenever $\pi < 1$ (and with strict equality for π sufficiently below 1). This implies $q_0 \geq \tilde{q}$. Hence $q_0 \geq \tilde{q}$ with strict equality for $\pi < 1$.

It remains to show that for $q > q_1$ it is optimal to reveal the information. We showed that

$$E[qR(\bar{q}_0; q) \,|\, q \in \bar{q}_0] \geq A, \tag{A17}$$

so that $q_1 R(y(q_1), q_1) > A$. Therefore for any $q \in m_i = [q_i, q_{i+1})$ and $q_i \geq q_1$ we have, $qR(y(q); q) > A$, as well as

$$E[qR(\bar{q}_i; q) \,|\, q \in m_i] \geq A. \tag{A18}$$

Hence, the impatient agent does not lose anything if the information is revealed on that interval as he gets A in any case, while the patient agent prefers to obtain the information as he can choose his action optimally. So any positive interval m above $[q_0, q_1)$ is dominated by $m(q) = \{q\}$. Finally, we show that $E[qR(\bar{q}_0; q) \,|\, q \in \bar{q}_0] = A$. Suppose $E[qR(\bar{q}_0; q) \,|\, q \in \bar{q}_0] > A$. Then there is a ε such that the message $\hat{m}(q) = [q_0, q_1 - \varepsilon)$ is such that $E[qR(y(\hat{m}); q) \,|\, q \in \hat{m}] \geq A$ and $qR(y(q), q) > A$ for all $q \in [q_1 - \varepsilon, q_1]$. Then the original message is dominated by message $\hat{m}$ where $\hat{m}(q) = [q_0, q_1 - \varepsilon)$ for all q in that interval and $\hat{m}(q) = q$ for all $q \in [q_1 - \varepsilon, q_1)$. ∎

Proposition 5

Because the potential supply of secondary market investors is infinite by assumption, an equilibrium with active secondary markets at a particular location i exists if there is a size $A_i > 0$ of secondary markets such that given the associated optimal information design, the expected rents for entrants are exactly c_i.

Start from a guess for $A_i \geq S$ for location i. The analysis of the one-market case we have carried out in this paper implies that only one optimal design policy exists given this size of secondary markets, and that this policy is fully characterized by a threshold $\bar{q}_i$ below which the project is scrapped. Furthermore, the mapping from A_i to $\bar{q}_i$ is continuous (and, incidentally, fully characterized in proposition 2.) This, in turn, implies a continuous mapping from A_i to expected rents. Either that mapping contains c_i in its image, in which case an equilibrium with active secondary markets at location i exists, or the mapping does not achieve c_i in which case the only equilibrium is one where $A_i = 0$ and full information prevails at that location.

At any equilibrium where secondary markets are in fact active, there must be a probability that cash-in-the market pricing will prevail. Indeed, otherwise, rents are zero and entrants cannot recovery their entry costs. This establishes that cash-in-the-market pricing in any market where entry costs are strictly positive and completes the proof.

Remark 1 and remark 2

Consider a candidate price schedule $p(q)$ for project shares at date 1 where, in the context of this proof, the premise is that q is only observed by early investors. We know that $p(q) \geq S$ in any equilibrium and for almost all q . If $S < p(q) < qR$ then only early consumers supply their project shares and, upon observing that demand, potential buyers infer that q is distributed with strictly positive continuous density over $[\frac{p(q)}{R}, 1]$. It follows that demand for project shares is $\pi \frac{A}{p(q)}$. The only case in which this is an equilibrium, therefore, has $p(q) = A$ and $qR > A$. If $p(q) > qR$ then all potential sellers sell, from which buyers infer that q is distributed with strictly positive continuous density over $[0, \frac{p(q)]}{R}]$ so that demand is zero, which can not be an equilibrium. The only equilibrium, then, has $p(q) = \min(S, qR)$ if $qR < A$ and $p(q) = A$ if $qR \geq A$ exactly as in the full information case.

The argument is the same for remark 4 with $E(q|m(q))R$ playing the role of qR

Proposition 3

Assume that the (fully but privately informed) manager observes that $q < \bar{q}(\pi)$. Then, since $\alpha qR < M$, she chooses to scrap, as desired. The converse holds by the exact same logic and the compensation scheme, therefore, leads to exactly the desired policy.

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