Incentives for Information Production in Markets where Prices Affect Real Investment[1]

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Abstract

We analyze information production incentives for traders in financial markets, when firms condition investment decisions on information revealed through stock prices. We show that traders' private value of information about a firm's investment project increases with the ex ante likelihood the project will be undertaken. This generates an informational amplification effect of shocks to firm value. Information production by traders may exhibit strategic complementarities for projects that would not be undertaken in the absence of positive news from the stock market. A small decline in fundamentals can lead to a market breakdown where information production ceases, and investment and firm value collapse. Our theory sheds light on how productivity shocks are amplified over the business cycle. (JEL: G14, G31, E32)

1 Introduction

Financial markets play a vital role in the economy. Even when no capital issuance is directly involved – i.e., in secondary financial markets – market prices indirectly guide investment decisions in the real economy. A literature in financial economics provides empirical evidence on the real effects of prices in financial markets and studies the theoretical implications of models in which financial markets not only reflect the cash flows generated by traded assets but also affect those cash flows. This is known as the "feedback effect."[1]

Hayek (1945) argued that prices are key sources of information for guiding production and allocation decisions. Prices aggregate information from many different traders, providing information that would be hard to generate otherwise. Hayek was referring to prices of all goods and services in the economy, but the argument applies to stock prices also. Stock prices contain information that can guide the decisions of managers, capital providers, and other decision makers in the real economy. It is therefore important to understand the forces behind information production by traders in financial markets and how this information gets into market prices.

In this paper, we analyze a model of the incentives for financial-market traders to produce information when they take into account the informational feedback from the prices of traded securities to firms' investment decisions. The analysis generates a new insight on the interaction between financial markets and the real economy: we show that the feedback effect and the endogeneity of information production, make financial markets amplify small shocks in fundamentals into

[1]See a recent review article by Bond, Edmans, and Goldstein (2012).

large changes in real investments and firm values. The amplification may be very large. A small decrease in fundamentals can lead to a discontinuous drop in information production, investment, and firm values.

In the model, a firm has to decide between taking a new investment opportunity (growth option) or continuing with the current strategy (business as usual). In making the decision, the firm relies to some extent on information reflected in its stock price. This information gets into the stock price via the trading of speculators, who acquire information about the profitability of the growth option. These speculators can be thought of as institutional traders or individuals, who can investigate the prospects of the opportunity the firm faces and make profits by trading on the information they gather. The informativeness of the security price for the firm's decision depends on how many speculators choose to become informed. This is determined endogenously in equilibrium by a break-even condition, such that the marginal speculator's benefit from acquiring information does not exceed his cost of doing so.

The amplification result in this framework is based on two effects. First, speculators have stronger incentives to produce information about firms' growth opportunities when these opportunities are ex-ante more profitable. When ex-ante profitability decreases, the firm is less likely to pursue the growth opportunity. Then, the value of the security becomes less sensitive to the information about the growth opportunity, and so this information does not enable speculators to make high profits from trading the security. Hence, they are discouraged from producing the information. Second, the information produced in the financial market has a positive effect on firm value because it leads to more efficient investment decisions. When speculators are discouraged from producing information, the firm becomes less valuable. Together these two effects imply that a decrease in the profitability of growth opportunities leads to less information production, amplifying the decrease in firm value beyond the direct effect of the decrease in profitability.

As ex-ante fundamentals deteriorate further, the amplification mechanism is strengthened by the emergence of strategic complementarities among speculators. Strategic complementarities in our model result from the feedback effect. When ex-ante fundamentals are weak, the firm will only consider making the investment if the amount of information coming from the market is sufficiently large (and positive). Hence, in this region of the fundamentals, speculators' profits increase when more other speculators produce information, as this increases the chance that the firm will make the investment. Indeed, as ex-ante fundamentals get weaker and strategic complementarities emerge, a small deterioration in fundamentals can lead to a discontinuous collapse in information production, with associated large drops in investment activity and firm valuations.

We link our model to the literature on business-cycle fluctuations. We show that changes in the profitability of new investment opportunities can be amplified in our model leading to large changes in total factor productivity (TFP) and factor inputs (either labor or capital). These are two channels that have been identified by Chari, Kehoe and McGrattan (2007) as potential channels for large fluctuations over the business cycle. The drop in the profitability of new investment opportunities leads to a decrease in information production, which reduces productivity further and may cause firms to invest less. While there are many papers describing mechanisms for amplification over the business cycle, our mechanism is unique in that it involves changes in stock-market informativeness, which should be an important channel given the central role of the stock market in the real economy.

We also provide a welfare analysis. We show that the amount of information produced by speculators in equilibrium is very different from the amount that a social planner would choose. Speculators have stronger incentives to produce more information on investments which are more likely to be undertaken, whereas from a welfare perspective information is more valuable when the investment is close to a zero net present value, because in that case information can help make the right decision. This is reminiscent of Hirshleifer's (1971) discussion of different types of information and how markets may incentivize the production of information which is socially useless. We discuss policy implications of the model.

The remainder of the paper is organized as follows. In Section 2, we describe the basic model of feedback. Section 3 derives the equilibrium outcomes. In Section 4, we analyze the effect of expected project profitability on information production, and demonstrate the amplification result and the relation to business-cycle fluctuations. Section 5 discusses welfare implications, relation to existing literature, empirical implications. Section 6 concludes. All proofs are relegated to the appendix. Further results on welfare and belief dispersion are available in an online appendix.

2 A Model of Feedback

There is a firm that can take a decision $A \in \{0,1\}$. The decision about A can be thought of in very general terms, representing anything that affects the firm's value, e.g., CEO replacement decisions, organizational change etc. Throughout the paper we will interpret A as representing an investment opportunity and refer to A as a project choice.

The firm's value depends on the choice of A and the realization of a state of the world $\omega \in \{l, h\}$, where each state is ex-ante equally likely. If the firm takes project $A = 0$, its value is V_0 for sure. If the firm takes action $A = 1$ its value V_ω is state dependent and, without loss of generality, we assume $V_h > V_l$. We therefore refer to project $A = 0$ as the low risk project and $A = 1$ as the risky project.[2] To introduce some value of learning about the state of the world, we assume that the value maximizing project depends on ω. In particular $V_h > V_0 > V_l$, so that $A = 1$ is optimal in state $\omega = h$ and $A = 0$ is optimal in state $\omega = l$. Define by $\overline{V}$ the ex-ante expected value from taking the risky project $A = 1$:

$$\overline{V} \equiv \frac{V_l + V_h}{2}.$$

The firm's shares give a proportional entitlement to the final payoff, which is V_ω if the firm chooses the risky project and V_0 if it does not. Importantly, no other securities have payoffs that are contingent on ω. Markets are thus incomplete and spanning is endogenous to the firm's decision. An example of such a situation would be the gains from synergies in a hypothetical merger, where the actual

[2] Note that the results do not change significantly if one allows the low risk project to entail some risk.

gains will not be observed unless the merger takes place. Similarly, a firm might invest in a growth opportunity, but if the firm chooses not to do so, nobody could ever find out whether this investment would have been valuable, had the firm invested in it.

The shares are traded in a market similar to the one in Kyle (1985). We use functional forms that are standard in the microstructure literature and convenient for our analysis. There are three types of traders: liquidity traders, speculators, and a market maker. There is a mass of measure 1 of speculators who are risk neutral and indexed by $i \in [0,1]$. Each speculator can learn a noisy signal $s_i \in \{l, h\}$ about ω at cost $c > 0$. Denote by $\lambda > \frac{1}{2}$ the probability with which a signal is correct, i.e.,

$$\begin{aligned} \lambda &= prob\,(s_i = h|\omega = h) \\ &= prob\,(s_i = l|\omega = l)\,. \end{aligned}$$

Assume that, conditional on the realization of the state of the world, s_i is distributed independently across speculators.

After observing their own signal, each speculator can trade an amount x_i, where $x_i \in [-1, 1]$. That is, there are frictions (such as limited wealth) that constrain trade size to a maximum of 1. Denote by α the (endogenous) measure of speculators that become informed about ω. Liquidity traders submit a total order n which is normally distributed with 0 mean and variance σ^2. The presence of liquidity traders ensures that equilibrium prices only partially reveal the speculators' information. This allows speculators to make trading profits in equilibrium, without which they would not be willing to incur the cost of information production (see Grossman and Stiglitz, 1980). Liquidity traders are pure noise traders. We will get back to this point in the online appendix where we analyze welfare. Total order flow X is:[3]

$$X = n + \int_0^{\alpha} x_i di. \tag{1}$$

The total order flow is submitted to a risk neutral market maker who observes X, but not its components. He then sets the price equal to the expected value of the firm conditional on the order flow.[4]

An important ingredient in our model is the feedback from the price to the firm's investment. The firm's manager does not observe the state of the world ω. He observes the share price and uses this information to update his belief about ω and consequently about the optimal project. He then makes a decision about the project to maximize expected firm value given the information available to him from the price. Of course, this feedback effect is taken into account by the market maker when setting the price. For simplicity, we do not allow the firm to produce information in-house. However, our results do not require there to be *no* in-house information production. The important element is that there are some types of information that the market has an advantage in producing.

[3] Uninformed speculators in our model optimally choose not to trade, because they would incur a loss in expectation from trading.

[4] As in Kyle (1985), this can be justified as a result of a perfectly-competitive market-making industry.

3 Characterization of Equilibrium

3.1 Trading decisions and project choice

From risk neutrality and because each speculator is too small to have a price impact, we know that if speculators acquire information, they will trade the maximum size possible.[5] As will become clear later on, it is optimal for informed speculators to buy one unit upon observing the signal $s_i = h$ and to sell one unit following the signal $s_i = l$. As a result, by the law of large numbers, when the state is $\omega = h$ a measure $\alpha\lambda$ of speculators will buy, and a measure $\alpha(1-\lambda)$ will sell. Aggregate order flow is therefore $X = n + \alpha(2\lambda - 1)$. Conversely, when the state is $\omega = l$, aggregate order flow will be $X = n - \alpha(2\lambda - 1)$.

Observing the order flow, the market maker updates his beliefs. We define $\theta(X;\alpha) \equiv \Pr(\omega = h|X)$ as his updated probability that the state is h, given the observed order flow X and a belief about the measure of informed speculators α. By Bayes' rule,

$$\theta(X;\alpha) = \frac{\varphi(X - \alpha(2\lambda-1))}{\varphi(X - \alpha(2\lambda-1)) + \varphi(X + \alpha(2\lambda-1))}, \tag{2}$$

where $\varphi(n)$ is the density function of the normal distribution with mean 0 and variance σ^2. The risky project is worth taking if and only if the updated probability $\theta(X;\alpha)$ is sufficiently high, such that the updated NPV of the risky project is higher than that of the safe project:

$$V_h\theta(X;\alpha) + V_l(1-\theta(X;\alpha)) > V_0.$$

Since the normal distribution satisfies the monotone likelihood ratio property,

[5] Except when they expect the price to exactly equal the value, an outcome which does not arise in our model.

we know that $\theta(X;\alpha)$ is strictly increasing in X as long as $\alpha > 0$. Thus, there is a cut-off value $\overline{X}(\alpha)$ such that the risky project is optimal, given the information in the order flow, if and only if $X > \overline{X}(\alpha)$. The threshold $\overline{X}(\alpha)$ is defined by

$$V_h\theta(\overline{X}(\alpha);\alpha) + V_l\left(1 - \theta(\overline{X}(\alpha);\alpha)\right) = V_0. \tag{3}$$

Using (2), (3) and the normal density function, we can derive

$$\overline{X}(\alpha) = \frac{\sigma^2}{2\alpha(2\lambda - 1)} \ln \frac{1-\gamma}{\gamma}, \tag{4}$$

where

$$\gamma \equiv \frac{1}{2} + \frac{\overline{V} - V_0}{V_h - V_l}. \tag{5}$$

The parameter γ will turn out to be a convenient variable for comparative statics. If the range of firm values under the risky project, $V_h - V_l$, is constant, γ is a direct measure of the ex-ante profitability of the risky relative to the riskless project. When the risky project is ex-ante more valuable ($\overline{V} > V_0$), we have $\gamma > \frac{1}{2}$, while we have $\gamma < \frac{1}{2}$ for the opposite case ($\overline{V} < V_0$).

Note that the threshold $\overline{X}(\alpha)$ depends on the firm's (and market maker's) belief about the amount of trade due to the informed speculators. When $\gamma < \frac{1}{2}$, $\overline{X}(\alpha)$ is positive and decreasing in α. To see this, note that in the limit, if there is no informed trade ($\alpha = 0$), the firm would not invest in the risky project regardless of the order flow, and so $\overline{X}(\alpha)$ goes to ∞. As α becomes positive and increases, there is more information in the order flow, and so the firm would be willing to invest at some positive order flows (when $X > \overline{X}(\alpha)$), and the cutoff above which it invests decreases as α increases and there is more information in the market. Conversely, if $\gamma > \frac{1}{2}$, the threshold $\overline{X}(\alpha)$ is negative and increasing in α.

In a first step, we will solve for the equilibrium in the continuation game after all speculators have chosen whether or not to acquire information and trade on it as described before. An equilibrium of the continuation game then consists of the following: (a) A 'fair' price set by the market maker conditional on observed order flow, given a belief about α and the firm's investment policy, (b) an action A by the firm that maximizes its expected value conditional on the observed stock price, and beliefs about α and the pricing rule. Moreover, the beliefs must be correct in equilibrium.

Lemma 1 *For a given α, the continuation game has an equilibrium where the market maker uses the pricing rule:*

$$P(X) = \begin{cases} V_h\theta(X) + V_l\left(1 - \theta(X)\right) & \textit{if} \quad X > \overline{X}\left(\alpha\right) \\ V_0 \quad \textit{if} \quad X \leq \overline{X}\left(\alpha\right) \end{cases}, \tag{6}$$

and the firm takes the risky project if and only if

$$P(X) > V_0. \tag{7}$$

An important feature of the equilibrium given by (6) and (7) is that the risky project is taken if and only if it ought to be undertaken based on the information revealed to the market maker by the order flow. The market maker observes the order flow and sets a price that guides the firm to make the right decision in expectation. There are also equilibria without this feature. For example, when $\gamma < \frac{1}{2}$, there is an equilibrium where the market maker sets $P(X) = V_0$ for any X and the firm optimally always chooses the risk free project. In this case, it is ex-ante optimal to take the risk free project, and so, given that the price reveals no new information, this is what the firm does. Similarly, even when $\gamma > \frac{1}{2}$ there could be equilibria, where there is some $X^{'} > \overline{X}(\alpha)$ and a pricing rule where the price is V_0 below $X^{'}$. This can be an equilibrium if observing a price of V_0 (given this pricing rule) provides sufficiently strong information that the true state is $\omega = l$, such that the firm optimally chooses the riskless project. The equilibrium described in Lemma 1 is the only equilibrium that survives the slight modification of the model in which the firm can observe order flow directly. Given that prices are set under the implicit assumption that there are many competing market makers it would be plausible to assume that order flow is public information and thus also observed by the firm. We will therefore focus on the equilibrium in Lemma 1 for the continuation game.

3.2 Trading profits

We now analyze the equilibrium amount of information production. For this, we need to calculate the expected trading profits of an informed speculator, as a function of how many other speculators become informed. Denote by $\pi(\alpha)$ the expected profits in a candidate equilibrium in which a measure α of speculators become informed. Using $\overline{X}(\alpha)$ from (4), we get:

Lemma 2 *A speculator's optimal trading strategy is to buy on $s_i = h$ and to sell on $s_i = l$. The expected trading profit is then given by*

$$\pi(\alpha) = (2\lambda - 1)(V_h - V_l) \int_{\overline{X}(\alpha)}^{\infty} H(x;\alpha) dx, \tag{8}$$

where

$$H(x;\alpha) \equiv \frac{\varphi(x - \alpha(2\lambda - 1))\, \varphi(x + \alpha(2\lambda - 1))}{\varphi(x - \alpha(2\lambda - 1)) + \varphi(x + \alpha(2\lambda - 1))}. \tag{9}$$

3.3 Information acquisition in equilibrium

Speculators decide whether to acquire information by comparing the cost c to the profit $\pi(\alpha)$. Using $\widehat{\alpha}$ to denote the equilibrium level of α, an equilibrium with interim level of information production ($\widehat{\alpha} \in (0,1)$) is obtained when, given that a measure $\widehat{\alpha}$ of speculators choose to produce information, a speculator who acquires information breaks even in expectation:

$$\pi(\widehat{\alpha}) = c. \tag{10}$$

We focus on equilibria that are stable to small perturbations around $\widehat{\alpha}$. A stable equilibrium requires that the profit function $\pi(\alpha)$ is decreasing in α at the point solving (10).

Alternatively, there may be a corner solution for $\widehat{\alpha}$. An equilibrium with no information production ($\widehat{\alpha} = 0$) is obtained when, given that none of the speculators produce information, the cost of producing information is greater than the expected trading profit:

$$\pi(0) < c. \tag{11}$$

The opposite corner solution can occur if all speculators wish to acquire and trade on information, which happens when

$$\pi(1) \geq c. \tag{12}$$

We now solve for the equilibrium in information acquisition decisions, taking as given the equilibrium of the continuation game from Lemma 1. The characterization of equilibrium outcomes is different depending on whether the risky or the riskless project is ex-ante optimal. We first analyze the case where the risky project is ex-ante optimal.

3.4 Equilibrium outcomes

3.4.1 Equilibrium when the risky project is ex-ante optimal

When $\overline{V} > V_0$ (i.e., $\gamma > \frac{1}{2}$), the firm will choose the risky project in the absence of information about the underlying state ω. Proposition 1 characterizes the equilibrium outcomes for this case.

Proposition 1 *When the risky project $A = 1$ is ex-ante optimal ($\overline{V} > V_0$), there exists a unique equilibrium.*

(i) If $c \geq (2\lambda - 1) \frac{V_h - V_l}{2}$, no information is produced ($\widehat{\alpha} = 0$) and the firm always chooses $A = 1$.

(ii) If $c < (2\lambda - 1) \frac{V_h - V_l}{2}$, and $\pi(1) < c$ then we have an interior solution $\widehat{\alpha} \in (0, 1)$, while for $\pi(1) \geq c$ we have a corner solution $\widehat{\alpha} = 1$.

According to Proposition 1, no information is produced if the cost of information production is too high, whereas a positive measure of speculators choose to become informed if information is not too costly. This measure is pinned down uniquely by the cost of information production and the other parameters of the model.

3.4.2 Equilibrium when the riskless project is ex-ante optimal

Consider now the case $\overline{V} \leq V_0$ (i.e.,$\gamma \leq \frac{1}{2}$) so that the firm chooses the riskless project in the absence of further information about the state of the world. Proposition 2 characterizes the equilibrium outcomes for this case. Define by $\pi^{\max} \equiv \max_{\alpha \in [0,1]} \pi(\alpha)$ and $\alpha^{\max} \equiv \arg\max_{\alpha \in [0,1]} \pi(\alpha)$

Proposition 2 *When the riskless project is ex-ante optimal ($\overline{V} \leq V_0$):*

(i) There always exists an equilibrium with no information production ($\widehat{\alpha} = 0$).

(ii) If $c > \pi^{\max}$, then $\widehat{\alpha} = 0$ is the unique equilibrium and the firm always chooses the riskless project $A = 0$.

(iii) If $c \leq \pi^{\max}$, there exist multiple equilibria. There is always an equilibrium with $\widehat{\alpha} = 0$ and the firm chooses the riskless project. All other equilibria have $\widehat{\alpha} > 0$ and the firm chooses the risky project with positive probability. Specifically, (a) if $\alpha^{\max} \in (0,1)$, then there exist at least the following equilibria: $\widehat{\alpha}_1 = 0$, $\widehat{\alpha}_2 \in (0, \alpha^{\max}]$ and $\widehat{\alpha}_3 \in [\alpha^{\max}, 1)$ if $\pi(1) < c$ or $\widehat{\alpha}_3 = 1$ if $\pi(1) \geq c$. (b) If $\alpha^{\max} = 1$, then there exist at least the following equilibria: $\widehat{\alpha}_1 = 0$, $\widehat{\alpha}_2 \in (0,1)$ and $\widehat{\alpha}_3 = 1$. (c) Overall, there exists an open set of parameters for which there exists $\widehat{\alpha}_3 < 1$.

Unlike the case when the risky project is ex-ante optimal, there may now be multiple equilibria. There is always an equilibrium with no production of information. If the cost of information production is high ($c > \pi^{\max}$), this is the only equilibrium. Otherwise, there are additional equilibria with positive measures of informed speculators.

3.4.3 Discussion of equilibrium outcomes

Figure 1 depicts the expected trading profits as a function of the measure of speculators who choose to acquire information. The hump shaped curve is for the case where the riskless project is ex-ante optimal (here, $\gamma = 0.49$), while the downward sloping curve is for the opposite case (here, $\gamma = 0.51$). When the risky project is ex-ante optimal, trading profits are monotonically decreasing in α and hence there is a unique equilibrium. When the riskless project is ex-ante optimal, the profit function is hump-shaped, and hence there may be multiple equilibria. If the cost of information production is high enough (c'' in the figure), then the only equilibrium exhibits no information production. If the cost of information is lower (c' in the figure), then there are at least three equilibria. The case depicted in the figure generates three equilibria: $\widehat{\alpha}_1$, $\widehat{\alpha}_2$ and $\widehat{\alpha}_3$. Note that the equilibrium $\widehat{\alpha}_2 \in (0, \alpha^{\max})$ is on the increasing segment of the profit function and therefore unstable. The other two equilibria $\widehat{\alpha}_1$ and $\widehat{\alpha}_3$ are both stable and will be the focus of the subsequent discussion.

To understand the way equilibria depend on whether or not the risky project is ex-ante optimal, it is useful to isolate the underlying economic effects that a change in the number of informed traders has on each trader's profits. First, there is the standard effect in models of informed trading with exogenous investment (e.g., Grossman and Stiglitz (1980)). As more speculators become informed, the equilibrium price is closer to the value of the stock, and profits are reduced. This causes a downward slope in the profit function. We call this the *competitive effect*. It generates strategic substitutability in agents' decisions to produce information. Going back to the expression for profits in (8), this effect is captured by the fact that $H(x;\alpha)$ is decreasing in α (see Proof of Proposition 1).

Second, there is the effect caused by the endogeneity of the firm's investment decision, captured by the effect of α on $\overline{X}(\alpha)$. The direction of this effect depends on whether or not the risky project is ex-ante optimal. If the risky project is ex-ante optimal, the firm's 'default' action is $A = 1$. Additional information then leads the firm not to take risk some of the time, so that the overall likelihood

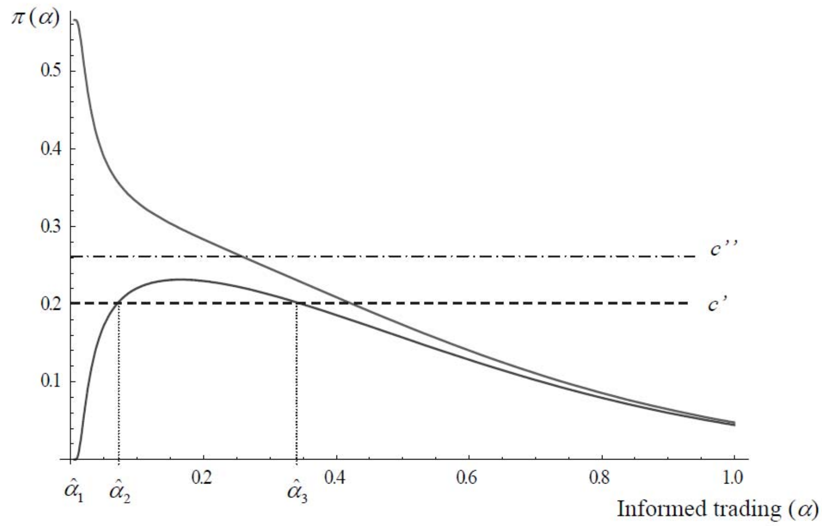

Figure 1: The figure shows trading profits as a function of the mass of informed traders α. The top line is for the case when the risky project is ex ante optimal. Parameter values are $V_h = 2.04, V_l = 0.04, V_0 = 1.02$ (hence, $\gamma = 0.51$). The bottom line is for the opposite case with parameter values $V_h = 2, V_l = 0, V_0 = 1.02$ (hence, $\gamma = 0.49$). Other parameter values are $\sigma^2 = 0.5$ and $\lambda = 0.9$. The figure also shows two different costs of information production c' and c'' and equilibrium values $\widehat{\alpha}_1, \widehat{\alpha}_2$ and $\widehat{\alpha}_3$ for c' and $\gamma = 0.49$.

of risk taking falls when more information becomes available ($\overline{X}(\alpha)$ increases in α). This reinforces the competitive effect because as more speculators produce information, the riskless project is taken more often and thus the value of the stock becomes less sensitive to the information produced, reducing speculators' incentives to produce information even further. Trading profits therefore decrease in α and the equilibrium is unique.

If the riskless project is ex-ante optimal, the firm's default choice is not to take risk. As speculators produce information, the firm may sometimes learn positive news and choose to take the risky project, namely when $X > \overline{X}(\alpha)$. Moreover, the threshold $\overline{X}(\alpha)$ decreases in α so that an increase in the number of informed speculators increases the likelihood that the firm takes the risky project. This renders firm value more sensitive to an individual speculator's private information. There is an *informational leverage effect*,[6] where information becomes more valuable as more agents produce it. Information production exhibits strategic complementarity. The interaction between the competitive effect and the informational leverage effect causes the profit function to be non-monotone.[7]

As a result of the non-monotonicity, we have multiple equilibria. First, there always exists the equilibrium $\widehat{\alpha}_1 = 0$ in which no information is produced.[8] This happens for the following reason. When nobody produces information, the firm never chooses the risky action. Then, the value of the firm's securities is

[6] We thank Rohit Rahi for suggesting this terminology.

[7] Boot and Thakor's (1997) model exhibits a similar non-monotonicity, although they do not explore this feature.

[8] Dow and Gorton (1997) also has multiple equilibria when the risky project is negative NPV. Because in that paper information is free, it corresponds to the two points on Figure 1 at zero information cost.

completely insensitive to the information that the speculator collected. He can therefore make no profit from trading and it is thus not worthwhile paying the cost to become informed.[9] Second, when the cost of information production is not too high ($c < \pi^{\max}$), there is a stable equilibrium $\widehat{\alpha}_3 \in (\alpha^{\max}, 1]$ with a strictly positive amount of information production. Figure 1 depicts the case where the equilibrium is given by an interior solution $\widehat{\alpha}_3 \in (\alpha^{\max}, 1)$. This is the more interesting case, because it allows us to conduct comparative statics on the equilibrium amount of information production - unlike the corner solution $\widehat{\alpha}_3 = 1$. In this equilibrium there is information production and trade, so that the firm chooses the risky action with sufficient likelihood to generate enough information sensitivity of the firm's securities. Although more informed trade would increase the information sensitivity of the firm's security further, this cannot be an equilibrium, because prices would become so revealing as to reduce trading profits below c.

Note also, that the equilibrium is discontinuous with respect to changes in fundamentals, e.g., the cost c of information production. Consider a cost c such that $\pi(1) < c < \pi^{\max}$ and therefore $\widehat{\alpha}_3 < 1$. As c increases from its initial level, $\widehat{\alpha}_3$ will fall continuously until $c = \pi^{\max}$ and $\widehat{\alpha}_3 = \alpha^{\max}$. At that point a small increase in c will lead to a discontinuous drop in the equilibrium amount of information production all the way to $\widehat{\alpha}_1 = 0$, which becomes the only possible equilibrium. We will explore this point in more detail in the next section.

[9] Note that this result does not depend on the 'low information' equilibrium coinciding with exactly zero information. One could allow a small fraction α_0 of speculators to be informed for free. For α_0 small, we would have $\pi(\alpha_0) < c$ and therefore no additional speculator would choose to become informed.

We now turn to a comparative static analysis of equilibrium information production with respect to the parameter γ. For this purpose, in case of multiple equilibria, we will focus on the most informative equilibrium. The notation $\widehat{\alpha}$ will refer to this equilibrium only, i.e., $\widehat{\alpha} \equiv \max\{\widehat{\alpha}_1, \widehat{\alpha}_2, \widehat{\alpha}_3\}$. We discuss the welfare ranking of multiple equilibria in an online appendix.

4 Information Production and Amplification

4.1 Profitability and information production

We analyze the effect of expected profitability of the risky project, measured by γ (as defined in (5)) on the equilibrium amount of information production $\widehat{\alpha}$. In varying γ, we wish to consider only the effect of the relative profitability of the risky action without changing anything else in the factors that determine $\widehat{\alpha}$. Inspecting the profit function in (8) and the expression for $\overline{X}(\alpha)$ in (4), which is key in determining the profit, we can see that this amounts either to changing V_0 or to changing $\overline{V}$, keeping $V_h - V_l$ constant.

Proposition 3 establishes the effect of γ on $\widehat{\alpha}$. Trivially, when the equilibrium is at either corner ($\widehat{\alpha} = 0$ if $c \geq \pi(0)$ or $\widehat{\alpha} = 1$ if $c \leq \pi(1)$), small changes in the model parameters will not affect the amount of information production. For the comparative statics presented in the following proposition we therefore focus on the stable interior equilibrium $\widehat{\alpha}_3 \in (\alpha^{\max}, 1)$.

Proposition 3 *Suppose parameters are such that the highest amount of information production in equilibrium $\widehat{\alpha} \in (0, 1)$. The amount of information production $\widehat{\alpha}$ then increases in γ.*

The intuition for this result is as follows. As the risky project becomes more profitable, for each level of information production, the firm chooses this project more frequently. Then, informed speculators' expected trading profits increase because the value of the firm is more exposed to the information about the profitability of the risky project. As a result, in equilibrium, more speculators choose to pay the cost of information, and the equilibrium amount of information increases.

4.2 Amplification

Utilizing the result above about the effect of the relative profitability of the risky project on information production, we now turn to analyze the effect of the ex-ante profitability of the risky project on the expected value of the firm. Recall that changes in γ could originate either from changes in the profitability of the risky project $\overline{V}$ or from changes in the profitability of the risk free project V_0. We focus here on changes in $\overline{V}$, which are more in line with the examples that motivate our analysis. Hence, we will refer to an increase in γ (originating from an increase in $\overline{V}$) as an increase in the fundamental of the firm. We ask what is the effect of improvement in the firm's growth option (increase in the firm's fundamentals) on the firm's value. Our main result is that endogenous information production amplifies the impact that such improvement has on the firm's expected value.

Since this section is concerned with the comparative static with respect to γ, we include γ as a function argument. Thus, let $V\left(\widehat{\alpha};\gamma\right)$ be the expected value of the firm as a function of the equilibrium amount of information produced $\widehat{\alpha}$ and the risky action's profitability γ. We showed above that the firm chooses the risky action whenever noise trading is above a certain threshold. In the good state ($\omega = h$), this threshold is $\overline{X}(\widehat{\alpha};\gamma) - \widehat{\alpha}(2\lambda - 1)$, while in the bad state ($\omega = l$), the firm chooses the risky action whenever n is above $\overline{X}(\widehat{\alpha};\gamma) + \widehat{\alpha}(2\lambda - 1)$. Hence, the expected value of the firm is

$$\begin{aligned} V(\widehat{\alpha};\gamma) &= \frac{1}{2}\left[\int_{\overline{X}(\widehat{\alpha};\gamma)-\widehat{\alpha}(2\lambda-1)}^{\infty} \varphi(n) V_h dn + \int_{-\infty}^{\overline{X}(\widehat{\alpha};\gamma)-\widehat{\alpha}(2\lambda-1)} \varphi(n) V_0 dn\right] \\ &\quad + \frac{1}{2}\left[\int_{\overline{X}(\widehat{\alpha};\gamma)+\widehat{\alpha}(2\lambda-1)}^{\infty} \varphi(n) V_l dn + \int_{-\infty}^{\overline{X}(\widehat{\alpha};\gamma)+\widehat{\alpha}(2\lambda-1)} \varphi(n) V_0 dn\right]. \end{aligned} \tag{13}$$

After performing changes of variables in both integrals and simplifying, this can be written as:

$$\begin{aligned} &V(\widehat{\alpha};\gamma) = V_0 \\ &\quad + \frac{1}{2}(V_h - V_l)\int_{\overline{X}(\widehat{\alpha};\gamma)}^{\infty} \left[\gamma\varphi(x - \widehat{\alpha}(2\lambda-1)) - (1-\gamma)\varphi(x + \widehat{\alpha}(2\lambda-1))\right] dx. \end{aligned} \tag{14}$$

We can now calculate how firm value changes in response to a change in the project's fundamentals, measured by γ.[10]

$$\frac{dV(\widehat{\alpha};\gamma)}{d\gamma} = \underbrace{\frac{\partial V}{\partial \gamma}}_{Direct\ Effect} + \underbrace{\frac{\partial V}{\partial \widehat{\alpha}} \cdot \frac{\partial \widehat{\alpha}}{\partial \gamma}}_{Indirect\ Effect}. \tag{15}$$

The first term in (15) captures the direct effect that a change in the project's characteristic has on firm value. The second term captures the indirect effect through the information channel. As the following proposition shows, the information channel amplifies the direct effect of fundamentals (γ) on firm value.

[10] Note that $\widehat{\alpha}$ and therefore $V(\widehat{\alpha};\gamma)$ may be discontinuous in γ so the following derivative is only defined on the continuous and differentiable segments of $V(\widehat{\alpha};\gamma)$. A discontinuity occurs when $\pi'(\widehat{\alpha}) = 0$.

Proposition 4 *Suppose that the highest equilibrium amount of information is an interior solution* $\widehat{\alpha} \in (0,1)$*:*

The endogenous response of information production to a change in the profitability of the risky project amplifies its direct effect on firm value:

$$\frac{dV(\widehat{\alpha};\gamma)}{d\gamma} = \frac{\partial V}{\partial \gamma} + \frac{\partial V}{\partial \widehat{\alpha}} \cdot \frac{\partial \widehat{\alpha}}{\partial \gamma} > \frac{\partial V}{\partial \gamma} > 0.$$

Intuitively, the direct effect, $\frac{\partial V}{\partial \gamma}$, is positive given that an increase in ex-ante profitability of the risky project directly increases the value of the firm. This is amplified by the indirect effect through the information channel, as $\frac{\partial V}{\partial \widehat{\alpha}} \cdot \frac{\partial \widehat{\alpha}}{\partial \gamma}$ is also positive. The mechanism behind the indirect effect reflects two forces. First, as we know from Proposition 3, the amount of information produced in the market increases when ex-ante profitability of the risky project improves ($\frac{\partial \widehat{\alpha}}{\partial \gamma} > 0$). Second, the presence of more information enables the firm to make a more efficient investment decision and this increases the value of the firm ($\frac{\partial V}{\partial \widehat{\alpha}} > 0$).[11]

Given the stylized nature of our model, it is obviously difficult to assess the quantitative significance of the amplification effect identified above. The next proposition demonstrates an important feature of the amplification effect, namely that it can sometimes be unboundedly large. Hence, in these cases, it ought to be quantitatively significant.

[11] We have analyzed a version of the model with three investment levels: Invest in the risky project in large scale, small scale, or not at all. We show that the presence of a corresponding option to expand (abandon) increases (decreases) equilibrium information production. Information now affects more decisions which strengthens the amplification effect.

Proposition 5 *Suppose* $\gamma < \frac{1}{2}$ *and* $c < \pi^{\max}$*, so that there exists an interior equilibrium* $\widehat{\alpha}_3 \in (\alpha^{\max}, 1)$*. Then there exists a* γ^* *such that the limit from above*

$$\lim_{\gamma \to \gamma^{*+}} \frac{\partial V}{\partial \widehat{\alpha}} \cdot \frac{\partial \widehat{\alpha}}{\partial \gamma} = \infty.$$

Moreover, $V(\widehat{\alpha}; \gamma)$ *is discontinuous in* $\gamma = \gamma^*$*.*

Intuitively, the information channel has the most drastic impact on firm value near the point where a small reduction in the risky project's fundamental γ drives out all informed trade. This happens near the point where the profit function reaches its maximum (Figure 1). At this point, a small decrease in γ causes informed trading to drop sharply, and in γ^*, discontinuously. Essentially, if the profit from information production worsens to the point where $c < \pi^{\max}$ no longer holds, then a positive amount of information can no longer be sustained in equilibrium and we drop to a unique equilibrium of $\widehat{\alpha} = 0$. This is the source of discontinuity in firm value with respect to project fundamentals.

The economic force behind this result is the presence of strategic complementarities in information production when the ex-ante relative profitability of the risky project is negative. In this case, the firm only invests if there is enough information in the price. Hence, a speculator finds it worthwhile to produce information when sufficiently many other speculators do so. A small decrease in fundamentals can then lead informed speculation to dry up completely in a *market breakdown*: traders stop producing information and abandon the market due to the correct expectation that others will do so as well. Since the market in our model has an important real effect in guiding resource allocation, this has a substantial negative effect on the firm's value.

4.3 Application to business cycle fluctuations

Although the firm's decision problem is very simple, it is sufficiently general to capture several possible applications. The firm has to take an action conditional on information, as with a real option. It could be an option to enter a new market or launch a new product if conditions are favorable. Similarly, a firm could decide to abandon a market or product following negative information. Under either scenario, one action, labelled $A = 1$ entails more risk than another, labelled $A = 0$.

We now discuss one application which we believe to be particularly relevant, namely where the risky action corresponds to a growth opportunity. V_0 can then be thought of as the expected firm value if the firm does not exercise the growth option. That value would be given by the value of the firm's cash holdings plus the net present value of its ongoing operations. Note that V_0 does not have to be literally a risk free payoff. All we need is that there is no private information available about V_0 so that speculators cannot profit when $A = 0$ is chosen. If $A = 0$ represents the company's status quo, it is quite plausible that there is no (or little) private information left on which speculators may trade. We can then think of γ as a measure of the profitability of growth opportunities. The parameter γ might differ across firms and over time.

We now develop the idea that γ may vary over time and be interpreted as a shock to firms production technology. A high γ can be thought of as 'good times' when firms have better new (and risky) investment opportunities. From the amplification result of Proposition 5, it is clear that small changes to the production technology may lead to large changes in firm value.[12]

Embedding our model in a fully dynamic general equilibrium model is beyond the scope of this paper. It is nevertheless interesting to speculate about the macroeconomic implications of our amplification mechanism. In order to do so, we will now discuss which margins of a Real Business Cycle (RBC) model our mechanism may affect and whether those margins are thought to be useful starting points as potential explanations of empirical patterns in business cycle fluctuations. Chari, Kehoe and McGrattan (2007) show that frictions in existing RBC models can be generally captured by four types of frictions in a prototype model: the labor wedge, the investment wedge, the efficiency wedge and government intervention. They argue that for RBC models to match observed output fluctuations, they must feature a significant efficiency wedge (fluctuations in total factor productivity, TFP) and/or a significant labor wedge. We will now discuss how our model can be thought of in terms of these two wedges.[13]

[12] In principle, one could think of a situation where a positive productivity shock increases the value of the risk free project relative to the risky project. Good times would then be associated with less information production and the information channel would work to attenuate the direct positive impact of the productivity shock, rather than amplify it. We believe it is more plausible to think of good times as being associated with more investment in new projects, rather than their abandonment.

[13] There is a literature that links business cycle fluctuations to capital market imperfections, for example, Bernanke and Gertler (1989), Greenwald and Stiglitz (1993), Kiyotaki and Moore (1997), and Suarez and Sussman (1997). Chari, Kehoe and McGrattan (2007) argue that the corresponding financial frictions translate into investment wedges, which are empirically less relevant. More recently, other papers link amplification and fluctuations to informational channels, e.g., Veldkamp (2005), Angeletos and La'O (2013), and Kurlat (2013). Our setting differs by linking changes in the economic outlook to endogenous changes in jointly-determined

4.3.1 TFP fluctuations

Suppose there is a measure one continuum of ex-ante identical firms, indexed by $j \in [0, 1]$. Each firm can choose between two projects – one is riskless and one is a risky growth opportunity – as described before. Growth opportunities are uncorrelated across firms, so that the success of each firm's risky project now depends on a firm-specific state of the world $\omega_j \in \{l, h\}$. For simplicity, assume that either project requires an identical amount of factor input I (which could be capital or labor) which is the only factor of production. These assumptions imply that all output fluctuations are due to productivity shocks and not changes in levels of input. This simplification allows us to clearly identify the TFP channel. Below we discuss what happens when input levels differ between $A = 0$ and $A = 1$.

Firm values were defined before as being net of the cost of taking an action A. We can then define output as $Y_0^j = V_0 + I$ if $A^j = 0$ is chosen and $Y_{\omega_j}^j = V_\omega + I$ if $A^j = 1$ is chosen. Total factor productivity of firm j, TFP_j, can then be defined as

$$TFP_j = 1 + \frac{V_{\omega_j}^{A_j}}{I},$$

where

$$V_{\omega_j}^{A_j} = \begin{cases} V_0 & \text{if} \quad A^j = 0 \\ V_{\omega_j} & \text{if} \quad A^j = 1 \end{cases}$$

We can then calculate how total factor productivity of this economy fluctuates with a change in γ, keeping the parameters V_0, I and $\Delta \equiv V_h - V_l$ constant (i.e., varying $\overline{V}$ only). This can be done by aggregating over all firms' realized

information production and investment behavior.

TFP_j, i.e., $TFP = \int_0^1 TFP_j dj$. Since there is a continuum of identical firms with uncorrelated projects, the realized TFP is just equal to the ex-ante expected TFP_j of an individual firm. Moreover, given that investment levels do not differ across actions, $E[TFP_j]$ can be calculated directly using the expected firm value $V(\widehat{\alpha};\gamma)$ from (14). From Proposition 4 it follows that a drop in the fundamental γ will lead to a direct reduction in measured TFP of the economy. Importantly, this direct effect is amplified through the information channel: A drop in γ reduces information production, which worsens resource allocation and thereby productivity. As before, a small drop of γ around γ^* leads to a discontinuous drop in information production and therefore to a discontinuous drop in measured TFP. Hence, small shocks to the production function (i.e., small shocks to γ) can be amplified into large shocks in measured TFP.

Figure 2 provides a numerical example. In the example, the TFP of the riskless project is normalized to 1, and γ fluctuates between 0.491 and 0.505; moving from $\gamma = 0.505$ to $\gamma = 0.491$ corresponds to a 2.9% drop in the NPV of the risky project. The solid line plots TFP when information production is endogenously given in equilibrium, while the dashed line gives TFP when information is exogenously fixed at $\widehat{\alpha}(\gamma = 0.505)$. As can be seen from the figure, the direct effect of a change in the fundamental is much smaller than the indirect effect. In the numerical example, the direct effect of a 2.9% drop in the NPV of the growth opportunity, has a direct effect of reducing TFP by 1.3%. Once the indirect effect is taken into account the drop in TFP amounts to 11.6%.

Importantly, the numerical example focuses on variations of γ around γ^*, which is obviously where amplification is most important. It is, however, quite

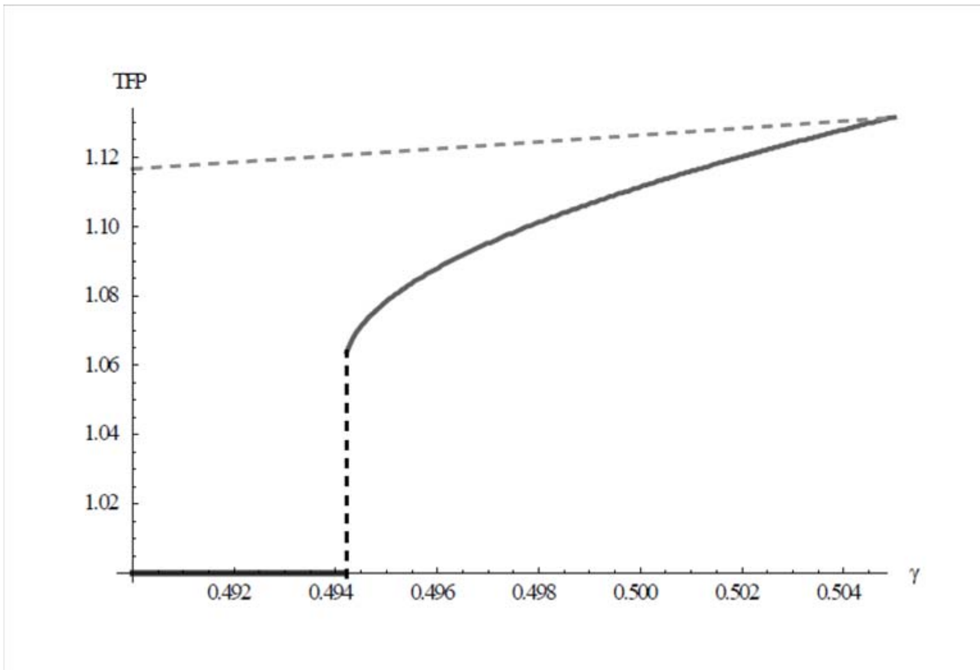

Figure 2: This Figure shows expected TFP as a function of γ. Parameter values are $V_h - V_l = 2, \sigma^2 = 0.7, c = 0.3, I = 1$. The TFP of the risk free investment is normalized to 1. The solid line gives TFP when information production is endogenously given in equilibrium. The dashed line gives TFP for α fixed at that level which would obtain in equilibrium when $\gamma = 0.505$, which corresponds to the highest γ plotted in the figure.

plausible to believe that this parameter range is particularly relevant in practice. If one thinks of γ as a property of the marginal investment project, it is quite plausible that it should be near the point of a zero NPV (absent further information). If the project were much more profitable ex-ante, it is likely that it would have been invested in already.

In summary, our model produces large fluctuations in measured TFP due to the endogenous changes in the efficiency of resource allocation, as it depends on information production in financial markets. We thus provide a microfoundation for why productivity shocks may be amplified. It would be interesting to embed our mechanism into a full-blown RBC model and to explore further the extent to which it can generate the kinds of efficiency wedges that Chari, Kehoe and McGrattan (2007) argue can explain observed business cycle fluctuations.

4.3.2 Fluctuations in factor inputs

We now extend the previous example to allow for varying levels of factor input (capital or labor), depending on whether project $A^j = 0$ or 1 is chosen. Denote by I_{A^j} the factor input corresponding to the project chosen by firm j. As before, we interpret the project $A^j = 1$ as an investment in a growth opportunity. Assume that $I_1 > I_0$, that is the factor input required for the growth opportunity is greater than that for the riskless project. We think this is the reasonable case to consider. Denote the aggregate factor input by $I_m = \int_0^1 I_{A^j} dj$. We can then conduct a comparative static with respect to γ keeping, as before, V_0, I_0, I_1, and Δ constant. We can again distinguish between a direct and an indirect effect:

$$\frac{dI_m}{d\gamma} = \frac{\partial I_m}{\partial \gamma} + \frac{\partial I_m}{\partial \widehat{\alpha}} \frac{\partial \widehat{\alpha}}{\partial \gamma}.$$

Proposition 6 *Suppose that $\widehat{\alpha} \in (0,1)$. The direct effect of an increase in the profitability of the risky project γ on aggregate factor input is positive, i.e.,*

$$\frac{\partial I_m}{\partial \gamma} > 0.$$

The indirect effect of an increase in γ is positive if $\gamma < \frac{1}{2}$ and negative if $\gamma > \frac{1}{2}$.

An increase in γ directly increases aggregate factor input, because firms are more willing to invest in the "high input" growth opportunity, i.e., the threshold $\overline{X}(\widehat{\alpha}; \gamma)$ falls. The sign of the indirect effect depends on the ex-ante profitability of the growth opportunity. If it is negative ($\gamma < \frac{1}{2}$), a firm's default action is not to invest in the growth opportunity and it needs to learn sufficiently positive news in order to be willing to invest. An increase in the amount of equilibrium information $\widehat{\alpha}$, resulting from an increase in γ, increases the likelihood of learning sufficiently positive news, increasing the aggregate input level further. The information channel therefore amplifies the direct effect of a change in γ.

Note that since $\gamma^* < \frac{1}{2}$, a small drop of γ around γ^* leads to a discontinuous drop in the aggregate input level. If information drops discontinuously to zero, the aggregate level of investment drops discontinuously to I_0: When all information production is driven out, firms cannot learn from prices and never invest in the growth opportunity since $\gamma < \frac{1}{2}$. Our model thus predicts potentially large fluctuations in factor demand as a response to small changes in the profitability of investment opportunities. It would be interesting to embed the model in a general equilibrium set-up so as to understand whether such demand fluctuations can have a significant impact on the amount of equilibrium investment and employment, which will presumably depend on the elasticity of factor supplies.

We believe this is a promising line of future research.

If $\gamma > \frac{1}{2}$ the indirect effect mitigates the direct effect of a change in γ on factor inputs. To see why, remember that at $\gamma > \frac{1}{2}$, a firm invests in the growth opportunity in the absence of information. More information therefore allows firms more often to avoid investing in the growth opportunity in the bad state of the world. More information therefore leads to a reduction in factor input.

5 Discussion

5.1 Welfare

We now investigate how the equilibrium amount of information production compares to the social optimum. Suppose the social planner cannot affect the way in which information gets communicated and therefore must rely on the price mechanism. He can, however, choose the mass of traders who pay the information production cost, e.g., by taxing / subsidizing trading activity.

A simple objective function for a social planner would be expected firm value net of the information production cost incurred by traders. Since trading profits are redistributive we ignore them in the social planner's problem. For a formal treatment and a more detailed derivation of the welfare function, see an online Appendix.[14]

It is then possible to show that information is socially most valuable for $\gamma = \frac{1}{2}$. This makes intuitive sense, since that is the point where the prior belief provides

[14]The Appendix also explores the policy option of taxing / subsidizing a firm's investment activity. This policy tool is relevant if direct trading subsidies lead to distortions in the form of spurious trading activity.

the weakest guidance as to what is the optimal decision. As γ moves away from $\frac{1}{2}$ (in either direction) the value of information drops monotonically and symmetrically. Again this is intuitive: as γ gets closer to 0 or 1, the prior provides a stronger indication of the optimal action and hence additional information is less valuable. Correspondingly, the socially optimal mass of informed traders is hump shaped, reaching a maximum at $\gamma = \frac{1}{2}$, and with bounds $\gamma_0 < \frac{1}{2}$ such that the socially optimal amount of information production is zero for $\gamma < \gamma_0$ and $\gamma > 1 - \gamma_0$.

Compare this to the equilibrium amount of information production and focus on the non-trivial case where c is small enough such that a positive amount of information is produced for some values of γ. From the previous discussion we know that there exists a γ^*, such that for $\gamma < \gamma^*$ equilibrium information production is zero, while it is positive and increasing for $\gamma \geq \gamma^*$. It is then straightforward to show that for relatively small values of γ we may get insufficient information production in equilibrium, while the opposite is true when γ is relatively large.

To see this, suppose $\gamma_0 < \gamma^* < 1 - \gamma_0$. When $\gamma \in (\gamma_0, \gamma^*)$ the equilibrium amount of information production is zero, but the socially optimal amount is strictly positive. Conversely, when $\gamma > 1 - \gamma_0$, the socially optimal amount of information production is zero, while the equilibrium amount is strictly positive.

These results can be linked to Hirshleifer's (1971) distinction between two types of information: discovery and foreknowledge. Discovery means learning information that will not necessarily be revealed otherwise, such as inventing a new technology. Foreknowledge means learning information that will in any case be revealed later on, such as learning a firm's earnings a few days in advance.

Only the first type of information is socially valuable, but private rewards may provide different incentives.

In our model, foreknowledge can be thought of as information about a project's cash flows when there is no or little uncertainty about whether the project will be undertaken (corresponding to a high γ). Discovery can be thought of as information needed to guide the decision on whether to take the risky project or not: if the project is not taken, information about ω will not become available. Our model shows that incentives provided by financial markets to generate discovery type information are systematically weaker than incentives to produce 'foreknowledge' (i.e., $\widehat{\alpha}$ increases in γ). The higher γ, the bigger the wedge between the social and the private value of information.[15]

5.2 Relation to literature

5.2.1 The real effects of financial markets

Our model contributes to a literature analyzing the role of market information in firms' decisions. Financial markets play a vital role in the economy even when no capital issuance is directly involved – i.e., in secondary financial markets. Market prices provide signals to decision makers and indirectly guide investment and other decisions in the real economy. This is valuable because markets gather information from many different participants, who are too numerous to commu-

[15] There is a vast recent literature highlighting different considerations in what makes information socially desirable or not. See, for example, Morris and Shin (2002), Angeletos and Pavan (2007), and Amador and Weill (2010).

nicate with the firm outside the trading process.[16] Due to high costs, incentive problems, and issues of conformity and corporate culture, the firm will arguably have difficulty in replicating this kind of information production internally. For example, Dow and Gorton (1997) argued that internal information production introduces agency problems in motivating information producers, while financial market traders can profit directly from their informed trades.[17] Our paper contributes to the theoretical literature by analyzing the incentives to produce information in a model where market prices have a feedback effect on firms' investments and cash flows.[18]

[16]For example, the literature on prediction markets shows that markets provide better forecasts than polls and other devices (see Wolfers and Zitzewitz (2004)).

[17]Traditional analysis of secondary financial markets with asymmetric information – e.g., Grossman (1976), Grossman and Stiglitz (1980), Hellwig (1980), Kyle (1985), Glosten and Milgrom (1985) – limits attention to assets whose cash flows are exogenous. There is, however, a literature that allows for the presence of feedback from prices to firm cash flows, among others, Fishman and Hagerty (1992), Leland (1992), Dow and Gorton (1997), Subrahmanyam and Titman (1999), Dow and Rahi (2003), Foucault and Gehrig (2008), Goldstein and Guembel (2008), Bond, Goldstein, and Prescott (2010), and Albagli, Hellwig, and Tsyvinski (2014). Empirical evidence in support of the allocational role of secondary market prices has been found by Baker, Stein, and Wurgler (2003), Luo (2005), and Chen, Goldstein, and Jiang (2007). A survey of the empirical and theoretical literature has been provided by Bond, Edmans, and Goldstein (2012).

[18]The few papers that allow for endogenous information production in this literature have a different focus from our work. Khanna, Slezak and Bradley (1994) explore the costs and benefits of insider trading by managers. Boot and Thakor (1997) and Dow and Gorton (1997)) compare bank and market financing. Fulghieri and Lukin (2001) and Hennessy (2009) study firms' choice between debt and equity. Strobl (2014) looks into the resolution of a managerial agency problem, while Huang, Kang and Gorton (2013) consider the interaction between corporate governance and CEO turnover. Finally, Peress (2014) incorporates the feedback effect in an

5.2.2 Strategic complementarities in information production

Our model generates strategic complementarities in information production when $\gamma < \frac{1}{2}$. These strategic complementarities are an important feature of our paper and lead to the extreme amplification of shocks to fundamentals. There is a recent literature developing different mechanisms that generate strategic complementarities in information acquisition, for example, Froot, Scharfstein and Stein (1992), Veldkamp (2006), Hellwig and Veldkamp (2009), Garcia and Strobl (2011), Ganguli and Yang (2009) and Goldstein and Yang (2015).

Our model identifies a novel mechanism generating such strategic complementarities, namely the feedback from the financial market to real investments.[19] There are two distinguishing features in our model relative to other papers of complementarities in information acquisition in financial markets. First, the involvement of the real sector in our model implies that complementarities have an effect on firm value and investment, and not just on prices like in other papers. Second, complementarities arise in our framework only when fundamentals are low – in particular, when the NPV of the investment is ex-ante negative – and so the extreme amplification arises only then. Hence, in contrast to the above papers, our theory predicts that amplification is more likely to arise when

endogenous growth model so as to explore the effect of wealth accumulation on information production. In contrast, our paper aims to investigate how information production leads to amplification of small changes in fundamentals into large (sometimes discontinuous) changes in investments and firm values. This result is new in the feedback literature.

[19] Angeletos, Lorenzoni, and Pavan (2012) and Goldstein, Ozdenoren, and Yuan (2011) generate strategic complementarities in trading due to a feedback effect, but do not consider information production.

fundamentals are relatively weak.

5.2.3 Uncertainty shocks

Exogenous uncertainty shocks

Bloom (2009) shows that (exogenous) uncertainty shocks can lead to significant output drops and argues that these are due to firms postponing investment decisions in response to higher uncertainty (see also Fernandez-Villaverde et al. (2011)). In terms of our model, an exogenous increase in uncertainty can be thought of as an increase in $\Delta = V_h - V_l$.

Our model delivers results similar to Bloom's findings when $\gamma > \frac{1}{2}$. Here, if there is very little uncertainty, the firm always invests. As uncertainty increases, it becomes more costly for the firm to invest (mistakenly) when the state of the world is bad. It thus requires more strongly positive information in order to invest. More uncertainty therefore decreases investment, as in Bloom (2009). On the other hand, when $\gamma < \frac{1}{2}$, and there is little uncertainty, the investment is only worth making when there is strongly positive news. As uncertainty increases, it becomes more costly for the firm to fail to invest (mistakenly) when the state of the world is good. Higher uncertainty therefore lowers the investment threshold and increases investment frequency.

Another channel by which uncertainty may affect γ is if agents in the model are risk averse and therefore discount risky cash flows more heavily. In that case an increase in uncertainty can be thought of as directly reducing $\overline{V}$ (in present value terms) and thereby γ. In that sense, an increase in uncertainty directly leads to a reduction in the equilibrium amount of information production.

Endogenous uncertainty shocks

An obvious question is whether changes in γ (driven by changes in $\overline{V}$) have an impact on endogenous measures of uncertainty. Since our model's focus is on information production, it seems most relevant to focus on the dispersion of beliefs about the underlying state of the world of the privately informed agents in the economy (all the others have homogenous beliefs). We can measure belief dispersion by the distance in beliefs of two agents who receive different private signals and then update based on publicly available information (order flow and price). We show that belief dispersion is decreasing in γ (for a formal treatment see the online appendix).

The intuition for this result is straightforward by now. A drop in γ reduces the equilibrium amount of information production $\widehat{\alpha}$. The stock price therefore conveys less information and agents know less about which state of the world pertains. Agents with private information therefore disagree more strongly. This result is in line with Bachmann, Elster and Sims (2013) who study disagreement among managers on the economic outlook based on surveys of managers in Germany and the US. Bachmann et al. view disagreement as a measure of uncertainty and show that it increases during economic downturns.

5.3 Empirical predictions

A central prediction of our paper is that information production in financial markets and hence price informativeness will increase when firms have better investment opportunities (Proposition 3). Testing this prediction requires a measure of investment opportunities and a measure of price informativeness.

There are various proxies for investment opportunities. Over time, we expect investment opportunities to be stronger in booms than in busts. In the cross section, innovative firms at the frontier of technology or firms with a high market-to-book ratio (growth firms) are likely to have better investment opportunities.

A prominent measure of price informativeness in the literature is price non-synchronicity (Roll, 1988), reflecting the extent to which a stock price moves independently of the market (see the survey by Morck, Yeung, and Yu (2013)). Another measure in the literature is the probability of informed trading measure (PIN) based on the structural model of Easley, Kiefer, and O'Hara (1996).

One could investigate other indicators of information production in the financial sector, such as analyst activity. Anecdotal evidence indeed suggests that financial firms' employment policies are more pro-cyclical than employment policies of other firms. In the cross section, McNichols and O'Brien (1997), Sun (2003), and Das, Guoh and Zhang (2006) document that analysts tend to follow firms with better prospects.

One possibility for empirical testing is to explore price informativeness (using the above measures) around the time of major corporate decisions. Mergers and acquisitions are a leading example, representing major investment opportunities for speculators to produce information. Our model predicts that they will produce more information when the acquisition is more likely to be completed. Completion is more likely when the initial stock price reaction of the acquirer is more positive, indicating a high expected NPV of the acquisition. Hence, our model predicts that price informativeness of the acquirer's stock after the announcement of the acquisition, will be higher if the market reaction to the announcement is more positive. Some acquisitions have large break-up fees, making them unlikely to be cancelled (see Luo, 2005), so we also predict greater price informativeness if there is a larger break-up fee.

Another set of predictions of our model is related to the amplification results in Proposition 4 and Proposition 5. First, the information channel amplifies the effect of shocks to investment opportunities on firm value and TFP[20]. Second, this effect may be very large when investment opportunities are expected to be less profitable.

One way to test the first prediction is to compare different types of firms over the business cycle. We predict that TFP and investment behaviour fluctuations should be stronger for growth firms, because they are more sensitive to our amplification mechanism. According to our model, Growth firms rely more on market information, and should tend to exhibit stronger sensitivity of investment to price. Also, our amplification mechanism is specific to traded securities; it is not relevant to private firms. Hence, we expect TFP to exhibit stronger business cycle fluctuations for public firms than for similar private firms.

Concerning the second prediction, our model suggests that TFP and investments will be more volatile in busts than in booms, and this will coincide with differences in the volatility of price informativeness.

Finally, our analysis has potential implications for asset pricing variables such as price volatility, trading volume, and perhaps risk premia, although one would need to embed our mechanism in a fully-fledged dynamic asset pricing model to

[20] This effect may also contribute to the fact documented by Eisfeldt and Rampini (2006) that there is much less capital re-allocation among firms during recessions than in booms.

spell them out. Based on the model presented here, informed trading increases in good times for growth firms, and this should make their trading volume more procyclical. Also, informed trading is more volatile for growth firms in bad times, and this should lead to an increase in their price volatility at those times. While information should also have first-order implications for risk premia and their behavior over the cycle, since our model does not feature risk aversion, we do not speculate here on the exact predictions and leave it for future research.

6 Conclusion

Financial markets play a central role in the economy. Most financial markets are secondary markets, which have no direct effect on capital investment, but whose market prices aggregate information that affects real investment decisions and consequently firm value. The model developed in this paper helps understand some consequences of this feedback effect by endogenizing the amount of information produced by market traders.

We show that speculators have stronger incentives to produce information about an investment opportunity when the firm is more likely to undertake the investment. This creates an amplification effect whereby small changes in fundamentals are amplified into large changes in real investments and firm values. Importantly, our model generates a market breakdown, where a small change in fundamentals can lead information production to dry up completely, generating a collapse in investment and firm value.

Amplification of small changes in fundamentals is a central topic in economics. Our paper is the first one that links amplification to the informational role of financial markets. Information in financial markets gets produced by speculators who are motivated by trading profits. This leads them to produce more information in good times than in bad times (or more information about good firms than about bad firms), generating our amplification mechanism. Given that information asymmetries are among the most important frictions driving investment and financing behavior, we believe that our informational channel is an important addition to the understanding of amplification in investment and firm values. We discuss some related empirical evidence and new empirical predictions and propose a new avenue for exploration in the dynamic real business cycle literature.

7 Appendix

Proof of Lemma 1: We first verify that the decision rule in (7) is optimal for the firm. This holds because observing a price above V_0 reveals that the updated belief about $\omega = h$ is sufficiently positive such that taking the risky project $A = 1$ is optimal. A price of V_0 reveals the opposite. Second, the pricing rule in (6) reflects the expected value of the firm given the order flow, and given the firm's investment decision: the price is equal to V_0 when the risky project is not expected to be taken and is equal to expected firm value when the risky project is taken. QED.

Proof of Lemma 2: Consider a speculator who receives $s_i = h$ and buys. With probability λ the state is $\omega = h$ and the speculator earns $V_h - P(X)$ if $X > \overline{X}(\alpha)$ and zero if $X \leq \overline{X}(\alpha)$. With probability $1 - \lambda$ the state is $\omega = l$ and the speculator earns $V_l - P(X)$ if $X > \overline{X}(\alpha)$ and zero if $X \leq \overline{X}(\alpha)$. Moreover, since in state $\omega = h$ we have $X = n + \alpha(2\lambda - 1)$ and in state $\omega = l$ we have $X = n - \alpha(2\lambda - 1)$ we get

$$\begin{aligned} E[\pi|s_i = h] &= \lambda \int_{\overline{X}(\alpha) - \alpha(2\lambda-1)}^{\infty} (V_h - P(n + \alpha(2\lambda - 1)))\,\varphi(n)\,dn \\ &\quad + (1-\lambda) \int_{\overline{X}(\alpha)+\alpha(2\lambda-1)}^{\infty} (V_l - P(n - \alpha(2\lambda - 1)))\,\varphi(n)\,dn. \end{aligned}$$

Using the price function (6) and (2), we can rewrite the expected profit of a speculator after observing a positive signal as:

$$\begin{aligned} &E[\pi|s_i = h] \\ &= \lambda(V_h - V_l) \int_{\overline{X}(\alpha)-\alpha(2\lambda-1)}^{\infty} \frac{\varphi(n + 2\alpha(2\lambda-1))}{\varphi(n) + \varphi(n + 2\alpha(2\lambda-1))} \varphi(n)\,dn \\ &- (1-\lambda)(V_h - V_l) \int_{\overline{X}(\alpha)+\alpha(2\lambda-1)}^{\infty} \frac{\varphi(n - 2\alpha(2\lambda-1))}{\varphi(n) + \varphi(n - 2\alpha(2\lambda-1))} \varphi(n)\,dn. \qquad (16) \end{aligned}$$

Conducting the change of variable $x = n + \alpha(2\lambda - 1)$ to the first line and $x = n - \alpha(2\lambda - 1)$ to the second line yields

$$\begin{aligned} &E[\pi|s_i = h] \\ &= \lambda(V_h - V_l) \int_{\overline{X}(\alpha)}^{\infty} \frac{\varphi(x + \alpha(2\lambda-1))}{\varphi(x - \alpha(2\lambda-1)) + \varphi(x + \alpha(2\lambda-1))} \varphi(x - \alpha(2\lambda-1))\,dx \\ &- (1-\lambda)(V_h - V_l) \int_{\overline{X}(\alpha)}^{\infty} \frac{\varphi(x + \alpha(2\lambda-1))}{\varphi(x - \alpha(2\lambda-1)) + \varphi(x + \alpha(2\lambda-1))} \varphi(x - \alpha(2\lambda-1))\,dx. \end{aligned}$$

This can be rewritten as

$$E[\pi|s_i = h] = (2\lambda - 1)(V_h - V_l) \int_{\overline{X}(\alpha)}^{\infty} H(x;\alpha)\,dx.$$

Going through the same line of reasoning for selling upon receiving $s_i = l$, yields an identical expression for $E[\pi|s_i = l]$.

Finally, note that $E[\pi|s_i = h] > 0$. Therefore, if the speculator were to sell on $s_i = h$, he would make a trading loss $-E[\pi|s_i = h]$ (and symmetrically for buying on $s_i = l$). It follows that the speculator's trading strategy is optimal. QED.

Proof of Proposition 1: We first show that when $\gamma > \frac{1}{2}$, $\pi(\alpha)$ is a strictly decreasing function. We can write

$$\frac{d\pi(\alpha)}{d\alpha} = \frac{d}{d\alpha}\left((2\lambda-1)(V_h - V_l)\int_{\overline{X}(\alpha)}^{\infty} H(x;\alpha)dx\right)$$
$$= (2\lambda-1)(V_h - V_l)\left[\int_{\overline{X}(\alpha)}^{\infty} \frac{\partial H(x;\alpha)}{\partial\alpha}dx - \frac{\partial\overline{X}(\alpha)}{\partial\alpha}H(\overline{X}(\alpha);\alpha)\right]. \quad (17)$$

First we show that $\frac{\partial H(x;\alpha)}{\partial\alpha} \leq 0$. Using the definition of $H(x;\alpha)$ as given in (9) and the fact that $\varphi'(n) = -\frac{n}{\sigma^2}\varphi(n)$ we can write

$$\frac{\partial H(x;\alpha)}{\partial\alpha}$$
$$= (2\lambda-1)H(x;\alpha)\frac{\left(\frac{x-\alpha(2\lambda-1)}{\sigma^2}\varphi(x+\alpha(2\lambda-1)) - \frac{x+\alpha(2\lambda-1)}{\sigma^2}\varphi(x-\alpha(2\lambda-1))\right)}{\varphi(x-\alpha(2\lambda-1)) + \varphi(x+\alpha(2\lambda-1))}.$$

We thus need to show that

$$(x-\alpha(2\lambda-1))\varphi(x+\alpha(2\lambda-1)) - (x+\alpha(2\lambda-1))\varphi(x-\alpha(2\lambda-1)) \leq 0$$

i.e.

$$x[\varphi(x+\alpha(2\lambda-1)) - \varphi(x-\alpha(2\lambda-1))] \quad (18)$$
$$\leq \alpha(2\lambda-1)[\varphi(x+\alpha(2\lambda-1)) + \varphi(x-\alpha(2\lambda-1))].$$

If $x < 0$, then, because φ is the density function of a normal distribution with mean 0, $\varphi(x+\alpha(2\lambda-1)) \geq \varphi(x-\alpha(2\lambda-1))$, and thus the LHS of (18) is negative while the RHS is positive, so the inequality in (18) holds. Similarly, if $x > 0$, then $\varphi(x+\alpha(2\lambda-1)) \leq \varphi(x-\alpha(2\lambda-1))$, and again the LHS of (18) is negative while the RHS is positive, so the inequality in (18) holds.

From (4) we can see that when $\gamma > \frac{1}{2}$, we will have $\ln \frac{1-\gamma}{\gamma} < 0$, and so $\frac{\partial \overline{X}(\alpha)}{\partial \alpha} > 0$. Thus, the second term in (17) is negative. It follows that $\frac{d\pi(\alpha)}{d\alpha} < 0$.

Thus, since $\pi(\alpha)$ is strictly decreasing the equilibrium is unique. There is a corner solution $\widehat{\alpha} = 0$ if $\pi(0) \leq c$ or $\widehat{\alpha} = 1$ if $\pi(1) \geq c$. The threshold on c follows from calculating $\pi(0) = (2\lambda - 1) \frac{V_h - V_l}{2}$. Otherwise, if $\pi(0) > c > \pi(1)$, there exists a unique interior intersection point $\pi(\alpha) = c$. QED.

Proof of Proposition 2: (i) We need to show that if $\widehat{\alpha} = 0$, the profit from producing information is 0. From (4), we can see that, for $\gamma < \frac{1}{2}$, $\lim_{\alpha \to 0} \overline{X}(\alpha) = \infty$. Substituting this in the profit function (8), and noting that $\lim_{\alpha \to 0} H(x;\alpha) = \frac{1}{2}\varphi(x)$, we know that $\lim_{\alpha \to 0} \pi(\alpha) = 0$.

(ii) This follows directly from the previous part and from the fact that $c > \pi^{\max}$.

(iii) From (8) it is clear that $\pi(\alpha) > 0$ for all $\alpha > 0$.

Next, we prove the following lemma.

Lemma 3 $\lim_{\alpha \to \infty} \pi(\alpha) = 0$.

Proof: Since as $\alpha \to \infty$, $\bar{X}(\alpha) \to 0$, for sufficient large α, we will have

$$\pi(\alpha) < (2\lambda - 1)(R_h - R_l) \int_{-1}^{\infty} \frac{\varphi(x - \alpha(2\lambda - 1))\varphi(x + \alpha(2\lambda - 1))}{\varphi(x - \alpha(2\lambda - 1)) + \varphi(x + \alpha(2\lambda - 1))} dx$$

Note that $\frac{\varphi(x-\alpha)\varphi(x+\alpha)}{\varphi(x-\alpha)+\varphi(x+\alpha)} < \varphi(x+\alpha)$, so

$$\begin{aligned} \pi(\alpha) &< (2\lambda - 1)(R_h - R_l) \int_{-1}^{\infty} \varphi(x + \alpha(2\lambda - 1)) dx \\ &= (2\lambda - 1)(R_h - R_l) \left[\int_{-1}^{1} \varphi(x + \alpha(2\lambda - 1)) dx + \int_{1}^{\infty} \varphi(x + \alpha(2\lambda - 1)) dx \right]. \end{aligned}$$

Since $\lim_{\alpha \to \infty} \varphi(x + \alpha(2\lambda - 1)) = 0$, $\lim_{\alpha \to \infty} \int_{-1}^{1} \varphi(x + \alpha(2\lambda - 1)) dx = 0$. For $\int_{1}^{\infty} \varphi(x + \alpha(2\lambda - 1)) dx$, note that when $x \geq 1$ and $\alpha \geq 0$, $\varphi(x + \alpha(2\lambda - 1)) =$

$\frac{1}{\sqrt{2\pi}\sigma}e^{-\frac{1}{2\sigma^2}(x+\alpha(2\lambda-1))^2} < \frac{1}{\sqrt{2\pi}\sigma}e^{-\frac{1}{2\sigma^2}(x+\alpha(2\lambda-1))}$, we have

$$\begin{aligned}
& \int_1^\infty \varphi(x+\alpha\,(2\lambda-1))dx \\
< \ & \int_1^\infty \frac{1}{\sqrt{2\pi}\sigma}e^{-\frac{1}{2\sigma^2}(x+\alpha(2\lambda-1))}dx = \frac{1}{\sqrt{2\pi}\sigma}2\sigma^2 e^{-\frac{1}{2\sigma^2}(1+\alpha(2\lambda-1))} \to 0 \text{ as } \alpha \to \infty
\end{aligned}$$

so $\lim_{\alpha\to\infty}\int_1^\infty \varphi(x+\alpha\,(2\lambda-1))dx = 0$. Thus $\lim_{\alpha\to\infty}\pi(\alpha) = 0$. QED

From the three properties (a) $\pi\,(0) = 0$,(b) $\lim_{\alpha\to\infty}\pi\,(\alpha) = 0$ and (c) $\pi\,(\alpha) > 0$ for all $\alpha > 0$, it follows that $\pi\,(\alpha)$ achieves its global maximum for some finite and positive value of α. The rest of the characterization follows directly. Finally, to be sure that an interior solution $\widehat{\alpha}_3$ exists for some parameters, it suffices to provide an example, which is done in Figure 1. QED

Proof of Proposition 3: We start by analyzing the effect of γ on trading profits $\pi\,(\alpha)$ for any level of information production α.

$$\frac{\partial\pi\,(\alpha)}{\partial\gamma} = (2\lambda-1)\,(V_h - V_l)\left[\int_{\overline{X}(\alpha)}^\infty \frac{\partial H(x;\alpha)}{\partial\gamma}dx - \frac{\partial\overline{X}\,(\alpha)}{\partial\gamma}\cdot H(\overline{X}\,(\alpha)\,;\alpha)\right] \quad (19)$$

Since $H(x;\alpha)$ does not depend on γ (see the definition of 9), we have $\frac{\partial H(x;\alpha)}{\partial\gamma} = 0$. Moreover, for any finite $\overline{X}\,(\alpha)$ we have $H(x;\alpha) > 0$. From (4), it follows that $\frac{\partial\overline{X}(\alpha)}{\partial\gamma} < 0$. Hence, $\frac{\partial\pi(\alpha)}{\partial\gamma} > 0$.

By the implicit function theorem we have $\frac{\partial\widehat{\alpha}}{\partial\gamma} = -\left(\frac{\partial\pi(\widehat{\alpha})}{\partial\gamma}\right)/\left(\frac{\partial\pi(\widehat{\alpha})}{\partial\widehat{\alpha}}\right)$. Since $\widehat{\alpha}_3$ is on the downward sloping segment of the profit function, it follows that $\frac{\partial\widehat{\alpha}_3}{\partial\gamma} > 0$. QED

Proof of Proposition 4: We know from the proof of Proposition 3 that $\frac{\partial\widehat{\alpha}}{\partial\gamma} > 0$. Hence, to prove the proposition, we need to show that $\frac{\partial V}{\partial\gamma} > 0$ and $\frac{\partial V}{\partial\widehat{\alpha}} > 0$.

Based on the expression for $V(\widehat{\alpha};\gamma)$ in (14), we know that:

$$\frac{\partial V(\widehat{\alpha};\gamma)}{\partial\gamma}$$
$$=\frac{1}{2}(V_h-V_l)\int_{\overline{X}(\widehat{\alpha};\gamma)}^{\infty}\left[\varphi\left(x-\widehat{\alpha}(2\lambda-1)\right)+\varphi\left(x+\widehat{\alpha}(2\lambda-1)\right)\right]dx.$$
$$-\frac{1}{2}(V_h-V_l)\frac{\partial\overline{X}(\widehat{\alpha};\gamma)}{\partial\gamma}\left[\gamma\varphi\left(\overline{X}(\widehat{\alpha};\gamma)-\widehat{\alpha}(2\lambda-1)\right)-(1-\gamma)\varphi\left(\overline{X}(\widehat{\alpha};\gamma)+\widehat{\alpha}(2\lambda-1)\right)\right].$$

Using (2) and (3), we can see that the expression in the brackets in the second line is 0. Since the expression in the first line is positive, we know that $\frac{\partial V}{\partial\gamma}>0$.

Now we can write:

$$\frac{\partial V(\widehat{\alpha};\gamma)}{\partial\widehat{\alpha}}$$
$$=\frac{1}{2}(V_h-V_l)\int_{\overline{X}(\widehat{\alpha};\gamma)}^{\infty}\left[-\gamma\varphi'\left(x-\widehat{\alpha}(2\lambda-1)\right)-(1-\gamma)\varphi'\left(x+\widehat{\alpha}(2\lambda-1)\right)\right]dx.$$
$$-\frac{1}{2}(V_h-V_l)\frac{\partial\overline{X}(\widehat{\alpha};\gamma)}{\partial\widehat{\alpha}}\left[\gamma\varphi\left(\overline{X}(\widehat{\alpha};\gamma)-\widehat{\alpha}(2\lambda-1)\right)-(1-\gamma)\varphi\left(\overline{X}(\widehat{\alpha};\gamma)+\widehat{\alpha}(2\lambda-1)\right)\right].$$

The second line is again 0. The first line can be rewritten as:

$$\frac{1}{2}(V_h-V_l)\left[\gamma\varphi\left(\overline{X}(\widehat{\alpha};\gamma)-\widehat{\alpha}(2\lambda-1)\right)+(1-\gamma)\varphi\left(\overline{X}(\widehat{\alpha};\gamma)+\widehat{\alpha}(2\lambda-1)\right)\right], \tag{20}$$

which is positive. Hence, $\frac{\partial V}{\partial\widehat{\alpha}}>0$. QED.

Proof of Proposition 5: First, the existence of a $\gamma<\frac{1}{2}$ yielding an interior $\widehat{\alpha}$ follows directly from the fact that $\pi(\alpha;\gamma)$ is increasing in γ. Hence, it suffices to choose a c such that $c<\pi^{\max}_{\gamma=\frac{1}{2}}$, but $c>\pi(\alpha=1;\gamma)$.

We know from (20) that

$$\left.\frac{\partial V}{\partial\widehat{\alpha}}\right|_{\widehat{\alpha}>0}>0.$$

Hence, we need to show that $\frac{\partial\widehat{\alpha}}{\partial\gamma}$ approaches ∞ as γ approaches γ^* from above. Define γ^* by that value of γ for which $\pi(\alpha^{\max})=c$ and therefore $\widehat{\alpha}=\alpha^{\max}$. By the implicit function theorem,

$$\frac{\partial\widehat{\alpha}}{\partial\gamma} = -\left(\frac{\partial\pi\left(\widehat{\alpha}\right)}{\partial\gamma}\right) / \left(\frac{\partial\pi\left(\widehat{\alpha}\right)}{\partial\widehat{\alpha}}\right).$$

From the proof of Proposition 3, $\frac{\partial\pi(\widehat{\alpha})}{\partial\gamma} > 0$. Since $\pi\left(\widehat{\alpha}\right)$ is differentiable, it follows that

$$\left.\frac{\partial\pi\left(\alpha\right)}{\partial\alpha}\right|_{\alpha=\alpha^{\max}} = 0$$

and therefore $\left.\frac{\partial\widehat{\alpha}}{\partial\gamma}\right|_{\gamma=\gamma^*} = \infty$.

$V\left(\widehat{\alpha};\gamma\right)$ is continuous in $\widehat{\alpha}$ and γ. The discontinuity of $V\left(\widehat{\alpha};\gamma\right)$ in γ^* follows directly from the discontinuity of $\widehat{\alpha}$ in γ^*. The latter follows from the fact that $\pi\left(\alpha\right)$ achieves its global maximum at the equilibrium point $\widehat{\alpha} > 0$ when $\gamma = \gamma^*$. QED

Proof of Proposition 6: First we calculate

$$I_m = \frac{I_0+I_1}{2} + \frac{I_1-I_0}{2}\left[1-\phi\left(\overline{X}\left(\alpha;\gamma\right)-\alpha\left(2\lambda-1\right)\right)-\phi\left(\overline{X}\left(\alpha;\gamma\right)+\alpha\left(2\lambda-1\right)\right)\right].$$

The direct effect can be calculated as

$$\frac{\partial I_m}{\partial\gamma} = -\frac{\partial\overline{X}\left(\alpha;\gamma\right)}{\partial\gamma}\frac{I_1-I_0}{2}\left[\varphi\left(\overline{X}\left(\alpha;\gamma\right)-\alpha\right)+\varphi\left(\overline{X}\left(\alpha;\gamma\right)+\alpha\right)\right].$$

Since $\frac{\partial\overline{X}(\alpha;\gamma)}{\partial\gamma} < 0$ it follows that the direct effect is positive.

Next we calculate

$$\begin{aligned}\frac{\partial I_m}{\partial\widehat{\alpha}} &= \frac{I_1-I_0}{2}\left\{\frac{\overline{X}\left(\widehat{\alpha};\gamma\right)}{\widehat{\alpha}}\left[\varphi\left(\overline{X}\left(\widehat{\alpha};\gamma\right)-\widehat{\alpha}\right)+\varphi\left(\overline{X}\left(\widehat{\alpha};\gamma\right)+\widehat{\alpha}\right)\right]\right.\\ &\qquad\left.+\left(2\lambda-1\right)\left[\varphi\left(\overline{X}\left(\widehat{\alpha};\gamma\right)-\widehat{\alpha}\right)-\varphi\left(\overline{X}\left(\widehat{\alpha};\gamma\right)+\widehat{\alpha}\right)\right]\right\}.\end{aligned}$$

This expression is positive if and only if $\overline{X}\left(\widehat{\alpha};\gamma\right) > 0$ which is the case if and only if $\gamma < \frac{1}{2}$. QED

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