

# Choosing to Disagree in Financial Markets

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## Abstract

In an otherwise canonical model of trade in a competitive financial market, we show that investors who experience anticipation utility systematically choose to deviate from rational expectations in their interpretation of both private and price information. When aggregate risk tolerance is low, the unique equilibrium is symmetric and investors optimally choose to exhibit overconfidence in their private information but dismiss the information in prices. However, when risk tolerance is sufficiently high, such symmetric equilibria do not exist. Instead, investors endogenously exhibit bias heterogeneity: one type ignores the information in prices, while the other chooses to overweight the price signal. Since belief choices are endogenous, our analysis sheds light on the conditions under which empirically relevant behavioral biases (e.g., overconfidence, dismissiveness) naturally arise. Finally, we characterize settings in which welfare is higher under the chosen subjective beliefs than under rational expectations.

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# 1 Introduction

Prices are an essential source of information because they aggregate disperse data about payoffs and preferences (see [Hayek \(1945\)](#) for an early discussion). As such, the standard approach in economics assumes that market participants have rational expectations and, therefore, learn efficiently from prices. Yet there is ample evidence that people do not behave this way: returns exhibit excess predictability and volatility, investors are overconfident and trade too often, and individuals appear to under-react to prices in some settings but over-react in others.<sup>1</sup> To explain this evidence, the existing literature has explored how informational frictions, endowed behavioral biases, and cognitive limits affect how investors process private and public signals.<sup>2</sup> However, they provide little guidance in understanding when such distortions arise because agents are constrained to exhibit such behavior by assumption. In this paper, we ask a more fundamental question: given a *choice*, how do investors interpret the information available to them, including that reflected in prices?

To address this question, we require a model of subjective belief choice. In standard expected utility theory, an investor is *endowed* with objective beliefs that affect utility only through their role in the weighing of future outcomes. In contrast, the motivated beliefs literature suggests that an individual also derives direct utility from her subjective beliefs through the anticipation of such future events.<sup>3</sup> The individual *chooses* her subjective beliefs together with her actions to maximize this “anticipated utility,” subject to the cost of deviating from the rational expectations benchmark.<sup>4</sup> Intuitively, this leads individuals to exhibit “wishful thinking”: they tend to choose beliefs that make them happy about the future, provided that they are not too far from the objective truth. We analyze whether investors who derive anticipated utility choose to adopt rational expectations and, if not, study which biases arise endogenously and under what conditions.

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<sup>1</sup>For instance, [Shiller \(1981\)](#) documents that stock returns exhibit excess volatility relative to fundamentals, and [Jegadeesh and Titman \(1993\)](#) document that stocks exhibit momentum. [Odean \(1999\)](#) documents that individual investors exhibit over-confidence as evidenced by excessive trading. Recent work by [Coibion and Gorodnichenko \(2012\)](#) suggests professional forecasters are slow to update their beliefs about macroeconomic variables, while [Greenwood and Shleifer \(2014\)](#) document that investor expectations of future returns exhibit extrapolation.

<sup>2</sup>These approaches include models of overconfidence (e.g., [Daniel, Hirshleifer, and Subrahmanyam \(1998\)](#)), differences of opinions (e.g., [Banerjee, Kaniel, and Kremer \(2009\)](#)), rational inattention (e.g., [Kacperczyk, Van Nieuwerburgh, and Veldkamp \(2016\)](#)), cursedness (e.g., [Eyster, Rabin, and Vayanos \(2018\)](#)), and costly interpretation of prices (e.g., [Vives and Yang \(2017\)](#)).

<sup>3</sup>See [Bénabou and Tirole \(2016\)](#) for a recent survey of the related literature on motivated beliefs, and [Brunnermeier and Parker \(2005\)](#) and [Caplin and Leahy \(2019\)](#) for frameworks that we build on.

<sup>4</sup>In the optimal expectations model of [Brunnermeier and Parker \(2005\)](#), the cost of distorting beliefs arises because these subjective beliefs lead to suboptimal decisions under the objective probability measure. In the wishful thinking model of [Caplin and Leahy \(2019\)](#), the agent incurs a direct disutility from distorting her beliefs (which depends on the Kullback-Leibler divergence between the subjective and objective beliefs).

Our analysis shows that, when given a choice, investors who experience anticipated utility always choose to deviate from holding objective beliefs. In any symmetric equilibrium, we show that investors choose to overweight their private information; surprisingly, however, they also choose to dismiss the information in prices.<sup>5</sup> These contrasting predictions are particularly striking in the context of our model. Investors do not face informational or cognitive frictions (e.g., they observe the price costlessly and are fully attentive to information) and trade in a perfectly competitive market.<sup>6</sup> Moreover, prices are incrementally informative for each investor — as in noisy rational expectations equilibria, the price aggregates the private information of other investors efficiently.

Formally, our analysis extends an otherwise standard model in which a continuum of symmetric, risk-averse investors trade a single risky asset against noise traders in a perfectly competitive market (à la Hellwig (1980)). Investors are privately informed about the risky payoff and can condition on prices when submitting their demand schedules. Each investor chooses her perceived precision of both her private signal and the information contained in the price, subject to a cost of distorting her beliefs away from the objective distribution.<sup>7</sup> For instance, an investor’s *anticipated* utility is higher if she believes that her signal is more informative than it actually is. Such beliefs increases the utility she derives today from her anticipation of future trading gains. But, such a deviation carries an objective cost: the investor’s position will be suboptimal from the perspective of the objective distribution and hence the average *ex-post*, experienced utility will be lower in the future. We refer to this as the *experienced utility* penalty.<sup>8</sup> For robustness, we also consider an alternative approach which imposes a cost that depends only on the statistical distance between the subjective and objective beliefs.<sup>9</sup>

The key to understanding our results is that, in a speculative setting, each investor prefers not only to be better informed, but also to have information that is not shared by

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<sup>5</sup>An overconfident investor, who believes her signal is more informative than it is, necessarily puts relatively less weight on the information in the price when updating her beliefs. We show that, in addition to such an effect, the investor optimally chooses to believe that the price is less informative than it objectively is, which further amplifies this distortion in her updating process.

<sup>6</sup>In a perfectly competitive market, any single individual investor’s choice of beliefs do not affect the price or the chosen actions of other investors.

<sup>7</sup>One can view the benchmark rational expectations approach as a special case of our model in which the cost of deviations in beliefs is infinite.

<sup>8</sup>More concretely, an investor’s anticipated utility is her expected utility from her (distorted) trading strategy, under the subjective distribution, while her average ex-post utility is her expected utility from the same (distorted) trading strategy, under the objective distribution. The investor’s optimal choice of subjective beliefs trades off these two measures of expected utility. As we discuss in Section 3, this is analogous to the “optimal expectations” approach of Brunnermeier and Parker (2005).

<sup>9</sup>As we discuss in the next section, this is in line with the approach taken by Caplin and Leahy (2019), and mirrors the approach taken in the large literature on robust control.

others, i.e., she *chooses to disagree* with other investors. In general, when she believes her information to be more precise than it actually is, an investor perceives less uncertainty and can trade more aggressively, which increases her anticipated utility. We refer to this as the **information channel**. In equilibrium, this channel leads investors to exhibit overconfidence in their private signal.

The information channel also applies when the information available in prices improves, e.g., when other investors’ aggregated information is more informative. However, subjective beliefs about such information affect anticipated utility through an additional channel. Believing that the price is more informative necessarily implies a price that tracks fundamentals more closely; for instance, because other investors are trading on better, or less correlated, information. This reduces the potential gains from speculating against others which, in turn, reduces anticipated utility — we term this the **speculative channel**.<sup>10</sup> The offsetting effect of this speculative channel can actually dominate the informational channel, leading investors to dismiss the information contained in prices.

We show that the relative effect of these two channels on an individual’s optimal subjective beliefs depends on the beliefs and behavior of other market participants in equilibrium. In any symmetric equilibrium, with any well-behaved cost function, investors overweight their private information but underweight the information in prices. This under-reaction to price information arises because the strength of the speculative channel increases with the weight other investors place on the price signal. If all other investors rationally condition on the information in the price, an individual investor always deviates and underweights the price: the speculative channel dominates. As a result, when aggregate risk tolerance is low, we show there exists a unique, symmetric equilibrium in which all investors completely ignore the information in prices even when subject to the benchmark experienced utility penalty.<sup>11</sup>

However, when aggregate risk tolerance is sufficiently high, we find that there cannot exist a symmetric equilibrium. Instead, an asymmetric equilibrium can arise in which the majority of investors ignore the price, but a minority overweight the information in the price. In such cases, the price is sufficiently informative so that for a small subset of investors, the information channel dominates. Intuitively, the benefit from the reduction in posterior

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<sup>10</sup>In the limit, if the price is perfectly informative, there are no speculative gains from trading. There may still be a gain from the risk premia earned by holding the risky asset, which reflects the compensation for bearing aggregate risk.

<sup>11</sup>In our benchmark, with the experienced utility penalty, agents exhibit behavior akin to the “fully cursed” agents of [Eyster et al. \(2018\)](#) or that found in a pure “differences of opinion” framework (e.g., found in [Banerjee et al. \(2009\)](#), [Banerjee \(2011\)](#)). Agents do not distort their beliefs in their private signal but fail to condition on the information found in prices. Under alternative frameworks, we show that overconfidence arises along with dismissiveness (“cursedness”).

variance outweighs the cost from lower trading gains, especially since most other investors are choosing to ignore the information in prices. This equilibrium highlights an important consequence of allowing investors to choose their subjective beliefs: endogenous investor polarization.<sup>12</sup> Such heterogeneity does not commonly arise in standard models where investors are simply assumed (constrained) to exhibit rational expectations or specific behavioral biases. In contrast, because investors endogenously choose their beliefs in response to the behavior of others, our model can generate richer equilibrium outcomes. Further, this is heterogeneity in kind, not simply in degrees: the two types do not exhibit varying levels of dismissiveness, but instead their beliefs about whether prices convey information are exactly opposite.

Our analysis complements the existing behavioral economics literature by characterizing how wishful thinking can endogenously give rise to behavioral biases that have usually been studied in isolation (e.g., over-confidence, dismissiveness, cursedness). Our predictions highlight that these deviations can arise under different economic conditions and may interact with each other in novel ways. For instance, our model implies that in settings with high aggregate risk tolerance (e.g., for stocks with high institutional ownership or during periods with high intermediary capital), prices are more informative about fundamentals and return predictability (serial correlation in returns) is positively related to return volatility and measures of liquidity. In contrast, when aggregate risk tolerance is low, prices are less informative about fundamental, and return predictability is negatively related to volatility. Our model also predicts a non-monotonic relation between return predictability and trading volume and volatility: return autocorrelation should be highest for stocks with intermediate volume and volatility, but lower for stocks in either extreme.

Our analysis also sheds light on the observed heterogeneity in investment styles. Fundamental, or “value”, investors that try to identify “mispriced” securities and tend to rely more on their private valuation of stocks are analogous to the over-confident, dismissive investors in our model. On the other hand, “technical” analysis and momentum strategies are based on extrapolating price changes, which is reminiscent of the overweighting of price information by the minority in our asymmetric equilibrium. The model predicts that such heterogeneity is more likely to arise when risk tolerance and price informativeness are high, for instance in more developed financial markets and larger (more widely held) stocks. More generally, our

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<sup>12</sup>In Brunnermeier and Parker (2005), general equilibria are analyzed in which some investors choose to be optimistic about an asset’s payoff. If such behavior distorts the price sufficiently upward, some agents choose to be pessimistic about the asset’s payoff which is equivalent to being *optimistic* about the potential trading gains. Effectively, beliefs are distorted for the same reason (though in different directions). In our asymmetric equilibrium, ex-ante well-being is the same across both types, but the channels through which this arises are distinct across the two types of investor.

analysis may help shed light on why some systematic deviations from rational expectations are prevalent in certain settings but not others, and why we sometimes observe seemingly opposing biases in the same market.

Finally, we characterize investor welfare in our setting and compare it to the rational expectations benchmark. Note that the expected utility of investors depends on the reference beliefs. We take a conservative stance on welfare by (i) evaluating expected utility under objective beliefs and (ii) focusing on the objective disutility that investors incur due to their subjective choices.<sup>13</sup> Using the objective measure, informed investors are always worse off than in a rational expectations equilibrium. However, we find that the noise traders are always better off because they incur a lower price impact on their trades relative to the rational expectations equilibrium. Surprisingly, we find that overall welfare (where we sum the objective expected utility across informed and liquidity traders) can be lower in the rational expectations equilibrium. This depends on the aggregate risk tolerance: welfare is lower under the rational expectations equilibrium when risk tolerance is sufficiently low, but higher otherwise.

The rest of the paper is as follows. Section 2 briefly discusses the phenomenon of anticipatory utility and reviews the related literature. Section 3 introduces the model setup and discusses our assumptions. Section 4 establishes the financial market equilibrium, given investor beliefs. Section 5 studies the tradeoffs associated with deviating from rational expectations. Section 6 studies a setting in which the investor chooses beliefs only about her private signal while in Section 7, we solve the more general setting. Section 8 collects the empirical implications of the model and Section 9 analyzes the impact on welfare implications. Section 10 concludes, and proofs and extensions can be found in the Appendices A and B, respectively.

## 2 Background and related literature

Bénabou and Tirole (2016) survey the now extensive literature on belief choice (e.g., Akerlof and Dickens (1982), Loewenstein (1987), Caplin and Leahy (2001), Eliaz and Spiegel (2006)). They emphasize that subjective beliefs can fill both psychological and functional needs for individuals. Our paper is related to the former channel, in which beliefs directly

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<sup>13</sup>Our measure of welfare is conservative in that it ignores the gain in anticipatory utility that investors experience by distorting their beliefs. Given that they choose to deviate from rational expectations, the investors' anticipated utility net of costs must be higher than under the rational expectations equilibrium (according to their subjective beliefs). However, from the perspective of a social planner who is restricted to objective beliefs, investors' expected utility is lower when they deviate from rational expectations because their demand for the risky asset is suboptimal.

enter the agent’s utility. We focus on the special class of models which utilize anticipatory utility: agents optimally manipulate their beliefs in order to improve their perception of the future, trading off such benefits against the costly mistakes they induce.

The concept of anticipatory utility, or current subjective expected utility, dates to at least [Jevons \(1905\)](#) who considers agents who derive contemporaneous utility not simply from current actions but also the anticipation of future utility flows. For instance, an agent who anticipates a positive *future* experience (e.g., the purchase of a new home) will experience a positive, *contemporaneous* utility flow (e.g., excitement about your new neighborhood). On the other hand, the prospects of a negative future outcome (e.g., the inevitability of declining health) can decrease an agent’s current utility (e.g., through anxiety or fear).

As a result, an agent’s subjective beliefs about future events will affect not just an agent’s actions but also her current utility. In this sense, beliefs directly enter the utility function as in the “affective” class of motivated beliefs literature (as labeled by [Bénabou and Tirole \(2016\)](#)). This creates a tension between holding beliefs that are “accurate” (and therefore will lead to optimal actions) and beliefs that are “desirable” (and therefore will increase current utility). We emphasize that agents do not suffer from a “multiple selves” problem but instead choose to hold a *single* set of beliefs which accounts for this implicit tradeoff. In particular, our assumption that deviations from the objective distribution are costly is a modeling convenience — we do not interpret the use of the objective distribution in specifying the cost as the agent “knowing” the true distribution. Instead, we wish to capture the notion that the agent behaves as if deviating too far from accurate beliefs is costly, either due to experience or because it reflects a departure from consensus.<sup>14</sup>

Like us, [Caplin and Leahy \(2019\)](#) also consider a setting in which agents engage in wishful thinking - they choose subjective beliefs to maximize anticipatory utility subject to a cost. In their case, the cost of choosing distorted beliefs depends upon the distance between the subjective and objective distributions. They show that subjective belief choice can help explain a number of behavioral biases, including as optimism, procrastination, confirmation bias, polarization and the endowment effect. We allow for general cost functions and show how endogenous belief choice can give rise to both overconfidence and under-reaction to price information (e.g., cursedness or dismissiveness) in financial markets.

In another closely related paper, [Brunnermeier and Parker \(2005\)](#) propose a model of optimal expectations in which agents maximize their expected wellbeing. In their model, agents choose prior beliefs to maximize anticipatory utility, and choose optimal actions subject to these priors. Unlike the “statistical distance” approach of [Caplin and Leahy \(2019\)](#), the cost of deviating from the objective distribution in [Brunnermeier and Parker \(2005\)](#) is

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<sup>14</sup>See [Caplin and Leahy \(2019\)](#) for a further discussion.

the loss in experienced utility as a result of actions that are sub-optimal under the objective distributions. This paper (along with [Brunnermeier, Gollier, and Parker \(2007\)](#)) apply this framework to understand risk-taking, preference for skewness, portfolio under-diversification and consumption/savings patterns. Our analysis considers similar behavior in a setting with asymmetric information (similar to [Hellwig \(1980\)](#)) where investors form beliefs not only about exogenous variables (fundamentals, signals) but also endogenous objects (equilibrium prices).<sup>15</sup>

While our analysis suggests that allowing for subjective belief choice yields a number of novel theoretical results, there is substantial empirical evidence that individuals do, in fact, choose to form motivated beliefs. Individuals engage in information avoidance, for instance, by choosing not to learn if you are at-risk of deadly disease even if the test is approximately costless ([Oster, Shoulson, and Dorsey \(2013\)](#)). At the same time, individuals may actively seek (and pay) to learn about potential good news, such as the outcome of a lottery-like event ([Ganguly and Tasoff \(2017\)](#)) or the performance of their portfolios on days when the market has done well ([Karlsson, Loewenstein, and Seppi \(2009\)](#)). Individuals also update asymmetrically when information is revealed: more weight is placed on good news, e.g., a positive signal about one’s IQ ([Mobius, Niederle, Niehaus, and Rosenblat \(2014\)](#)) than bad news, e.g. a negative signal about one’s attractiveness ([Eil and Rao \(2011\)](#)). Finally, many individuals interpret information in ways which are favorable to their current well-being, updating in ways consistent with their political beliefs ([Kahan \(2013\)](#)) or interpreting uninformative signals of ability as positive indicators ([Exley and Kessler \(2019\)](#)).

As discussed by [Caplin and Leahy \(2019\)](#), the wishful thinking approach we employ has a parallel in the robust control literature (e.g., [Hansen and Sargent \(2001\)](#), [Hansen and Sargent \(2008\)](#)). Agents who exhibit robust control are unsure about their model of the world, and choose actions optimally under the “worst-case” subjective beliefs. As in our setting, the set of plausible beliefs under consideration is restricted to be “close” to the objective distribution (usually, through a statistical penalty function like the Kullback-Leibler divergence).<sup>16</sup> The

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<sup>15</sup>As we discuss in Section 3, we specify the cost of deviating from objective beliefs as the disutility the agent experiences from choices made under subjective beliefs. As such, while the overall objective function resembles that of [Brunnermeier and Parker \(2005\)](#), we interpret it somewhat differently. As [Caplin and Leahy \(2019\)](#) suggest, the [Brunnermeier and Parker \(2005\)](#) approach may be interpreted as one with divided selves: the agent chooses subjective beliefs by evaluating outcomes under the objective distribution (at date zero), and chooses actions in the following periods by evaluating outcomes under the chosen subjective distribution. In contrast, agents in our model (as in [Caplin and Leahy \(2019\)](#)) evaluate outcomes only under the subjective beliefs, but their choice of subjective beliefs is anchored to be “close” to the objective distribution.

<sup>16</sup>As [Caplin and Leahy \(2019\)](#) highlight, a wishful thinking agent chooses action  $a$  and subjective beliefs  $\mu$  to solve:

$$\max_{\mu} \max_a \mathbb{E}_{\mu} [u(a)] - C(\mu), \tag{1}$$

where  $\mathbb{E}_{\mu} [u(a)]$  reflects the subjective expected utility from action  $a$  under beliefs  $\mu$  and  $C(\mu)$  reflects the



robust control approach is motivated by the large literature in psychology and economics that documents ambiguity aversion, and has been useful in understanding a number of stylized facts about aggregate financial markets (e.g., the equity premium puzzle). However, as emphasized by [Caplin and Leahy \(2019\)](#) (and suggested by the list of papers above), there is also substantial evidence for both optimism and motivated beliefs. Each type of behavior is likely to arise in different contexts, and our analysis suggests that accounting for wishful thinking may be an important step in understanding what gives rise to overconfidence and dismissiveness in financial markets.

Our paper contributes to two strands of the literature studying the financial market impact of deviations from rational expectations. The first strand focuses on differences of opinion, whereby investors “agree to disagree” about the joint distribution of payoffs and signals and therefore, incorrectly condition on the information in prices (e.g., [Harrison and Kreps \(1978\)](#), [Kandel and Pearson \(1995\)](#), [Banerjee et al. \(2009\)](#) and [Banerjee \(2011\)](#)). Other approaches that lead investors to discount the information in prices include models that feature rational inattention (e.g., [Kacperczyk et al. \(2016\)](#)), cursedness (e.g., [Eyster et al. \(2018\)](#)) and costly learning from prices (e.g., [Vives and Yang \(2017\)](#)).<sup>17</sup> The second, related strand focuses on the impact of overconfidence: specifically, settings in which agents believe their private information is more precise than it objectively is (e.g., [Odean \(1998a\)](#); [Daniel et al. \(1998\)](#); [Daniel, Hirshleifer, and Subrahmanyam \(2001\)](#); [Gervais and Odean \(2001\)](#)). These two strands highlight how such deviations can explain a number of stylized facts about financial markets that are difficult to reconcile in the rational expectations framework, including excess trading volume and return predictability. In contrast to the existing literature, however, we do not assume that investors exhibit differences of opinions or overconfidence. Instead, investors are allowed to choose their beliefs, and importantly, exhibiting rational expectations is within their choice set. As such, our analysis sheds light on the economic forces that may lead to behavior (e.g., overconfidence and dismissiveness) that deviates from the rational expectations benchmark.

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penalty of choosing subjective beliefs  $\mu$  that differ from the reference distribution. In contrast, a robust control agent chooses action  $a$  and subjective beliefs  $\mu$  to solve

$$\max_a \min_{\mu} \mathbb{E}_{\mu} [u(a)] + C(\mu), \tag{2}$$

where the agent chooses the optimal action  $a$  under the worse case beliefs  $\mu$ , subject to the penalty  $C(\mu)$  of deviating from the reference distribution.

<sup>17</sup>While [Eyster et al. \(2018\)](#) show that cursedness can generate distinct predictions from a model of differences of opinions (which they term dismissiveness) when there is imperfect competition and no noise trading, our setting features perfectly competitive markets and noise in prices, and so cursedness and differences of opinions are effectively isomorphic.

### 3 Model setup

**Asset payoffs.** There are two securities. The gross return on the risk-free security is normalized to one. The terminal payoff (fundamental value) of the risky security is  $F$ , which is normally distributed with mean  $m$  and prior precision  $\tau$  i.e.,

$$F \sim \mathcal{N}\left(m, \frac{1}{\tau}\right). \quad (3)$$

We denote the market-determined price of the risky security by  $P$ , and the aggregate supply of the risky asset by  $z$ , where

$$z \sim \mathcal{N}\left(0, \frac{1}{\tau_z}\right). \quad (4)$$

**Information.** There is a continuum of investors, indexed by  $i \in [0, 1]$ . Before trading, each investor is endowed with a private signal  $s_i$ , where

$$s_i = F + \varepsilon_i \quad \varepsilon_i \sim N\left(0, \frac{1}{\tau_e}\right) \quad (5)$$

and  $\varepsilon_i$  is independent and identically distributed across investors so that  $\int \varepsilon_i di = 0$ . Moreover, investors can update their beliefs about  $F$  by conditioning on the information in the price  $P$ .

**Beliefs and preferences.** Each investor  $i$  is endowed with initial wealth  $W_0$  and zero shares of the risky security, and exhibits CARA utility with coefficient of absolute risk aversion  $\gamma$  over terminal wealth  $W_i$ :

$$W_i = W_0 + x_i(F - P), \quad (6)$$

where  $x_i$  denotes her demand for the risky security. We allow each investor to interpret the quality of the information in both her private signals and the price subjectively. Specifically, we assume that investor  $i$  believes that the noise in her private signal is given by<sup>18</sup>

$$\varepsilon_i \sim_i \mathcal{N}\left(0, \frac{1}{\delta_{e,i}\tau_e}\right), \quad (7)$$

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<sup>18</sup>Here  $\sim_i$  denotes “distributed as, according to investor  $i$ ’s beliefs.”

and believes the distribution of the asset's aggregate supply, which as we show below is proportional to the noise in the signal investors can extract from the price, is given by

$$z \sim_i \mathcal{N} \left( 0, \frac{1}{\delta_{z,i} \tau_z} \right). \quad (8)$$

In what follows, we will denote the expectation and variance of random variable  $X$  under investor  $i$ 's beliefs about the information environment, i.e.,  $\delta_{e,i}$  and  $\delta_{z,i}$  by  $\mathbb{E}_i[X]$  and  $\text{var}_i[X]$ , respectively. As is standard, we will denote the expectation and variance of  $X$  under the true (objective) distribution by  $\mathbb{E}[X]$  and  $\text{var}[X]$ , respectively.

The parameters  $\delta_{e,i}, \delta_{z,i} \in [0, \infty]$  reflect the degree to which investor  $i$  over- or under-estimates the precision of the private signal and aggregate noise, respectively. When  $\delta_{e,i} = \delta_{z,i} = 1$ , investor  $i$ 's beliefs satisfy **rational expectations**: her beliefs coincide with the objective distribution of the underlying shocks. On the other hand, when  $\delta_{e,i} > 1$ , investor  $i$  is overconfident about her private signal: she believes her private signal is more informative than it objectively is and she overweights it in forming her beliefs. The opposite is true when  $\delta_{e,i}$  is less than one. Similarly, when  $\delta_{z,i} > 1$  ( $\delta_{z,i} < 1$ ), investor  $i$  believes the price to be more informative (less informative, respectively) about fundamentals. We assume that such deviations from the objective distribution impose a utility cost, denoted by  $C(\delta_{e,i}, \delta_{z,i})$ .

Given her choice of subjective beliefs, each investor optimally chooses her position in the risky security. Thus, optimally chosen subjective beliefs maximize her anticipated utility, net of cost  $C(\cdot)$ . Formally, denote investor  $i$ 's optimal demand, given her beliefs, by:

$$x_i^*(\delta_{e,i}, \delta_{z,i}) = \arg \max_{x_i} \mathbb{E}_i \left[ -\gamma \exp \{ -\gamma x_i (F - P) - \gamma W_0 \} \mid s_i, P \right]. \quad (9)$$

and denote investor  $i$ 's **anticipated utility** by

$$AU_i(\delta_{e,i}, \delta_{z,i}) \equiv \mathbb{E}_i \left[ \mathbb{E}_i \left[ -\gamma \exp \{ -\gamma x_i^* (F - P) - \gamma W_0 \} \mid s_i, P \right] \right]. \quad (10)$$

Then, investor  $i$  optimally chooses subjective beliefs  $\delta_{e,i}$  and  $\delta_{z,i}$  to maximize:

$$\max_{\delta_{e,i}, \delta_{z,i}} AU_i(\delta_{e,i}, \delta_{z,i}) - C(\delta_{e,i}, \delta_{z,i}). \quad (11)$$

We assume that the cost function  $C(\cdot)$  penalizes deviations from the objective distribution (i.e., from  $\delta_{e,i} = \delta_{z,i} = 1$ ) and is well-behaved as defined below.

**Definition 1.** A cost function  $C(\delta_{e,i}, \delta_{z,i})$  is **well-behaved** if  $C(1, 1) = \frac{\partial C}{\partial \delta_{e,i}}(1, 1) = \frac{\partial C}{\partial \delta_{z,i}}(1, 1) = 0$ , and  $C$  is strictly convex (i.e., its global minimum is at  $(1, 1)$ ).

While many of our results apply to general cost functions, our main analysis focuses on a special case in which the cost each investor incurs by distorting her subjective beliefs is the reduction in expected utility (under the *objective* distribution) when her position in the risky asset,  $x_i^*(\delta_{e,i}, \delta_{z,i})$ , is determined by the chosen *subjective* distribution. As is well-established, any deviation from the rational expectations benchmark ( $\delta_{e,i} = \delta_{z,i} = 1$ ) is objectively inefficient: the investor is over- or under-weighting the information she receives. We refer to this specification as the “experienced utility” penalty benchmark.

**Definition 2.** Investor  $i$  incurs the **experienced utility penalty** if the cost of choosing  $\delta_{e,i}, \delta_{z,i}$  is given by:

$$C_{obj}(\delta_{e,i}, \delta_{z,i}) \equiv \frac{\mathbb{E}[-\gamma \exp\{-\gamma x_i^*(\delta_{e,i}, \delta_{z,i}) \times (F - P) - \gamma W_0\}]}{-\mathbb{E}[-\gamma \exp\{-\gamma x_i^*(1, 1) \times (F - P) - \gamma W_0\}]} \quad (12)$$

As we show in the appendix, when investors incur the experienced utility penalty, their subjective belief choice problem can be represented as:

$$\max_{\delta_{e,i}, \delta_{z,i}} AU_i(\delta_{e,i}, \delta_{z,i}) + \mathbb{E}[-\gamma \exp\{-\gamma x_i^*(\delta_{e,i}, \delta_{z,i}) \times (F - P) - \gamma W_0\}]. \quad (13)$$

This is closely related to the objective function in the “optimal expectations” approach of [Brunnermeier and Parker \(2005\)](#). Under this approach, an investor optimally chooses actions under subjective beliefs  $\mathbb{E}_i[\cdot]$ , and the optimal choice of beliefs maximizes the investor’s well-being under the objective distribution i.e.,

$$\max_{\delta_{e,i}, \delta_{z,i}} \mathbb{E} \left[ \begin{array}{c} \mathbb{E}_i[-\gamma \exp\{-\gamma x_i^*(\delta_{e,i}, \delta_{z,i}) \times (F - P) - \gamma W_0\} | s_i, P] \\ -\gamma \exp\{-\gamma x_i^*(\delta_{e,i}, \delta_{z,i}) \times (F - P) - \gamma W_0\} \end{array} \right] \quad (14)$$

$$= \max_{\delta_{e,i}, \delta_{z,i}} \mathbb{E}[AU_i(\delta_{e,i}, \delta_{z,i})] + \mathbb{E}[-\gamma \exp\{-\gamma x_i^*(\delta_{e,i}, \delta_{z,i}) \times (F - P) - \gamma W_0\}]. \quad (15)$$

In our setting,  $AU_i(\delta_{e,i}, \delta_{z,i}) = \mathbb{E}[AU_i(\delta_{e,i}, \delta_{z,i})]$  and so the two objectives coincide. We utilize this cost function as our benchmark because of its clear interpretation, intuitive appeal and direct quantitative implications.

### 3.1 Discussion of assumptions

We emphasize that the penalty function in (12) does not necessarily imply that the investor knows the objective distribution; instead, it should be interpreted as a tractable specification for the utility cost of subjective beliefs, from the perspective of the modeler (or observer). This is in contrast to the interpretation of [Brunnermeier and Parker \(2005\)](#), where agents

choose their beliefs with knowledge of the objective distribution and then choose actions using their subjective model of the world. Intuitively, we interpret the above specification (and that of Brunnermeier and Parker (2005)) as one in which investors evaluate their actions and outcomes under a single, subjective model of the world, which is “close to the truth” in the sense that the distortions in behavior do not generate too large of a loss in experienced utility. The subjective model that is chosen may result from a more complicated process of experimentation, learning and experience, which trades off “desirable” models (that increase anticipated utility) against “accurate” models (that increase experienced utility). The specification in (12) provides a tractable characterization of this process from the perspective of economic modeling.

For ease of presentation, we capture each agent’s subjective beliefs about others through the parameter  $\delta_{z,i}$ . In Appendix B.1, we show that this parameterization effectively captures several alternative interpretations of investors’s subjective beliefs. Specifically, in addition to beliefs about the aggregate supply (modeled as liquidity demand in the appendix), investors can choose their beliefs about the precision of others’ signals and the correlation in their error terms. For instance, suppose investor  $i$  believes that the error  $\varepsilon_j$  is given by:

$$\varepsilon_j = \rho_i \eta + \sqrt{1 - \rho_i^2} u_i, \quad \eta, u_i \sim N\left(0, \frac{1}{\pi_i \tau_e}\right), \quad (16)$$

where  $\rho_i \in [-1, 1]$  parametrizes the correlation across others’ errors and  $\pi_i \in [0, \infty]$  parametrizes the precision of their signals. We show that, in equilibrium, such beliefs affect an agent’s utility only through their perception of the price signal’s informativeness and establish a formal mapping from  $\rho_i$  and  $\pi_i$  to  $\delta_{z,i}$ .

Our paper’s focus is on the manner and degree to which investors choose beliefs which imply disagreement with others - as such, we choose to focus on investors’ subjective beliefs about private signals. In Appendix B.2, we explore how investors form beliefs about a public signal observed by all agents in the economy.

As emphasized in our discussion of belief formation, motivated beliefs are also constrained beliefs: investors must be able to plausibly observe and weight available information in a fashion which supports their chosen beliefs. For tractability, we do not directly model this information processing and allow for wide-ranging investor beliefs: for instance, an investor can believe that their signal is perfectly informative. In Appendix B.3, we analyze the impact of bounding investor beliefs on equilibrium outcomes.

Finally, we assume that investors make their subjective belief choices *before* observing the realizations of their signals. This makes the analysis tractable: conditional on choosing their interpretation of  $s_i$  and  $s_p$ , we can show there exists a financial market equilibrium in

which the price is a linear signal about fundamentals. In Appendix B.4, we explore how our results are affected when investors choose their interpretations after observing the signals. Unfortunately, solving for the general equilibrium is not feasible: updating on the price signal is analytically intractable. However, the partial equilibrium analysis of a single investor's interpretation suggests that our main results are robust to this alternative specification: when signal realizations are sufficiently extreme, an investor chooses to overweight her private signal but underweight the information in prices. We hope to explore the further implications of this ex-post belief choice in future work.

## 4 Financial market equilibrium

We first solve for the financial market equilibrium, taking investors' chosen subjective beliefs as given. We consider equilibria in which the price  $P$  is a linear combination of fundamentals  $F$  and noise trading  $z$ , and conjecture that observing the price is equivalent to observing a signal of the form:

$$s_p = F + \beta z. \quad (17)$$

The variance of this signal is  $\tau_p^{-1} = \beta^2/\tau_z$ , and  $\beta$  is a constant determined in equilibrium. Given investor  $i$ 's subjective beliefs  $\delta_{e,i}$  and  $\delta_{z,i}$ , and conditional on her observed signals,  $s_i$  and  $s_p$ , investor  $i$ 's posterior subjective beliefs are given by:

$$F|s_i, s_p \sim_i \mathcal{N}\left(\mu_i, \frac{1}{\omega_i}\right), \text{ where} \quad (18)$$

$$\mu_i \equiv \mathbb{E}_i[F|s_i, s_p] = m + A_i(s_i - m) + B_i(s_p - m), \quad (19)$$

$$\omega_i \equiv \frac{1}{\text{var}_i[F|s_i, s_p]} = \frac{\tau}{1 - A_i - B_i}, \text{ and} \quad (20)$$

$$A_i \equiv \frac{\delta_{e,i}\tau_e}{\tau + \delta_{e,i}\tau_e + \delta_{z,i}\tau_p}, \text{ and } B_i \equiv \frac{\delta_{z,i}\tau_p}{\tau + \delta_{e,i}\tau_e + \delta_{z,i}\tau_p}. \quad (21)$$

The optimal demand for investor  $i$ , given her subjective beliefs, is given by

$$x_i^* = \frac{\mathbb{E}_i[F|s_i, P] - P}{\gamma \text{var}_i[F|s_i, P]} = \frac{\omega_i}{\gamma} (\mu_i - P). \quad (22)$$

Equilibrium prices are determined by market clearing:

$$\int_i x_i^* di = z, \quad (23)$$

which implies:

$$P = \frac{\int_i \omega_i \{m + A_i(F - m) + B_i(s_p - m)\} di}{\int_i \omega_i di} - \frac{\gamma}{\int_i \omega_i di} z \quad (24)$$

This verifies our conjecture for functional form of the price and we can write

$$\beta = \frac{-\gamma}{\int_i \omega_i A_i di} = -\frac{\gamma}{\tau_e \int_i \delta_{e,i} di}. \quad (25)$$

The above results are summarized in the following lemma.

**Lemma 1.** *Given investor  $i$ 's subjective beliefs  $\delta_{e,i}$  and  $\delta_{z,i}$ , there always exists a unique, linear, financial market equilibrium in which*

$$P = m + \Lambda(s_p - m), \text{ where } \Lambda = \frac{\int_i \delta_{e,i} \tau_e + \delta_{z,i} \tau_p di}{\int_i \tau + \delta_{e,i} \tau_e + \delta_{z,i} \tau_p di}, \quad (26)$$

$s_p = F + \beta z$ ,  $\tau_p = \tau_z / \beta^2$ , and  $\beta = -\frac{\gamma}{\tau_e \int_i \delta_{e,i} di}$ . When subjective belief choices are symmetric (i.e.,  $\delta_{e,i} = \delta_e$  and  $\delta_{z,i} = \delta_z$  for all  $i$ ), then the price is given by:

$$P = m + \Lambda(s_p - m), \text{ where } s_p = \left(F - \frac{\gamma}{\tau_e \delta_e} z\right), \Lambda = \frac{\delta_e \tau_e + \delta_z \tau_p}{\tau + \delta_e \tau_e + \delta_z \tau_p}, \text{ and } \tau_p = \frac{\tau_z \tau_e^2 \delta_e^2}{\gamma^2}. \quad (27)$$

As the above lemma makes apparent, the choice of investor beliefs affect equilibrium prices through two channels. First, an increase in the perceived precision of private signals (higher  $\delta_{e,i}$ ) increases the signal to noise ratio of the signal  $s_p$  (since  $|\beta|$  is decreasing in  $\delta_{e,i}$ ). Investors trade more aggressively on their private information which is then reflected in the objective quality of the information in the price. Second, an increase in the perceived precision of either private signals (i.e., higher  $\delta_{e,i}$ ) or price information (i.e., higher  $\delta_{z,i}$ ) increases the sensitivity of the price to fundamentals ( $F$ ) through  $\Lambda$ . These channels interact to affect a number of empirically observable features of the financial market equilibrium, which we characterize next.

## 4.1 Return and volume characteristics

Given the financial market equilibrium in Lemma 1, we characterize how the underlying parameters of the model, in combination with investors' choice of beliefs, affect observable return and volume characteristics and the degree to which prices reflect information. Since the risk-free security is the numeraire, the (net) return on it is zero. Consequently, the

(dollar) return on the risky security is given by

$$R \equiv F - P. \quad (28)$$

Furthermore, because the risky security is in zero net supply, the unconditional expected return is zero i.e.,  $\mathbb{E}[R] = 0$ . However, conditional on the price, the expected return can be expressed as:

$$\mathbb{E}[F - P|P] = m + \theta(P - m), \text{ where } \theta \equiv \frac{\text{cov}(F - P, P)}{\text{var}(P)}. \quad (29)$$

Here  $\theta$  reflects the degree to which the returns are predictable and, as such, we refer to it as the return predictability coefficient. The unconditional variance in returns is given by

$$\sigma_R^2 = \text{var}(F - P), \quad (30)$$

while the conditional variance in returns is characterized by

$$\text{var}(F - P|P) = \tau_p^{-1}. \quad (31)$$

Note that the conditional variance in returns is inversely related to one measure of price informativeness, as  $\tau_p$  reflects how precise the price signal is about fundamentals  $F$ . Finally, since investors start without an endowment of the risky security, trading volume in our economy can be characterized as

$$\mathcal{V} \equiv \int_i |x_i^*| di. \quad (32)$$

Given investor beliefs, the following result describes how these return-volume characteristics depend on the underlying parameters.

**Lemma 2.** *Consider the unique financial market equilibrium described in Lemma 1. Then,*

- (ii) *the unconditional variance in returns is  $\sigma_R^2 = \frac{(1-\Lambda)^2}{\tau} + \frac{\Lambda^2\beta^2}{\tau_z}$*
- (iii) *the return predictability coefficient is  $\theta = \frac{1}{\Lambda} \left( \frac{1/\tau}{\beta^2/\tau_z + 1/\tau} - \Lambda \right)$ ,*
- (iv) *price informativeness is  $\tau_p = \tau_z/\beta^2$ , and*
- (v) *expected trading volume is*

$$\mathbb{E}[\mathcal{V}] = \int_i \frac{\omega_i}{\gamma} |\mu_i - P| di = \int_i \frac{\omega_i}{\gamma} \sqrt{\frac{2}{\pi} \left( \frac{A_i^2}{\tau_e} + \frac{(B_i - \Lambda)^2 \beta^2}{\tau_z} + \frac{(A_i + B_i - \Lambda)^2}{\tau} \right)} di, \quad (33)$$

where  $\omega_i$ ,  $A_i, B_i$ ,  $\beta$  and  $\Lambda$  are defined in (20)-(21) and Lemma 1.



To provide intuition for the dependence of these equilibrium characteristics on the underlying parameters, we make use of the signal to noise ratio (or Kalman gain) for the price signal  $s_p$ , which can be written as

$$\kappa \equiv \frac{\text{var}(F)}{\text{var}(s_p)} = \frac{1/\tau}{\beta^2/\tau_z + 1/\tau} = \frac{\tau_p}{\tau + \tau_p}. \quad (34)$$

First, note that an increase in the price sensitivity  $\Lambda$  has two offsetting effects on return volatility. On the one hand, when the price is more sensitive to  $s_p$ , it reflects fundamentals more closely, and this decreases volatility (through the  $\frac{(1-\Lambda)^2}{\tau}$  term). On the other hand, a higher  $\Lambda$  also implies that the price is more sensitive to shocks to the asset supply, which increases volatility (through the  $\frac{\Lambda^2\beta^2}{\tau_z}$  term). The first effect dominates when the price sensitivity  $\Lambda$  is lower than the signal to noise ratio  $\kappa$  (i.e.,  $\Lambda < \kappa$ ), while the latter effect dominates when price sensitivity is higher.

Second, note that the return predictability coefficient is positive when the signal to noise ratio is higher than the price sensitivity (i.e.,  $\theta > 0$ ). In this case, prices exhibit drift — a higher price today predicts higher future returns. On the other hand, when the signal to noise ratio is lower than  $\Lambda$ , prices exhibit reversals. Comparing the expression of  $\kappa$  above to  $\Lambda$  in (26), prices cannot exhibit drift unless investors under-react to price information (i.e.,  $\delta_{z,i} < 1$ ). Conversely, when investors correctly interpret the precision of price information, the prices exhibit reversals (i.e.,  $\delta_{z,i} = 1$  implies  $\Lambda > \kappa$ ).<sup>19</sup> In particular, prices exhibit reversals when investors exhibit rational expectations. Such reversals arise because the aggregate supply of the asset is subject to transitory shocks and investors are risk-averse. Moreover, we note that holding fixed the signal to noise ratio  $\kappa$ , an increase in price sensitivity  $\Lambda$  decreases return predictability: even though an increase in  $\Lambda$  increases the covariance of  $F$  and  $P$ , this effect is swamped by the increase in the variance of the price.

Third, price informativeness,  $\tau_p$ , naturally decreases in the magnitude of  $\beta$  — when investors have less private information, the price is more sensitive to aggregate supply shocks.. Finally, note that volume reflects the cross-sectional variation across investor valuations (i.e.,  $\mu_i$ ), scaled by their posterior variance (i.e.,  $\omega_i^{-1}$ ). The variation is driven by three channels: (i) the weight each investor's beliefs place on the noise in their private signals (i.e., the  $\frac{1}{\tau_e}$  term), (ii) the relative weight on the noise in prices (i.e., the  $\frac{\beta^2}{\tau_z}$  term) and (iii) the relative weight on the true fundamental value (i.e., the  $\frac{1}{\tau}$  term). Note that the last term is absent in symmetric equilibria, since  $A_i + B_i = \Lambda$  in this case. However, in asymmetric equilibria, this final term reflects the variation in valuations due to asymmetric reaction to private signals and the information in prices (see Section 7.2).

<sup>19</sup>This is because, as we show below, in equilibrium investors never choose to set  $\delta_{e,i} = 0$ .

## 5 Anticipated utility and subjective beliefs

With the financial market equilibrium established, we can now characterize the optimal subjective beliefs of an investor. Importantly, we assume that each investor takes as given the subjective belief distortion chosen by other investors: she does not assume that other investors hold rational expectations.

Given the optimal demand for the risky asset (22), anticipated utility is given by

$$AU_i(\delta_{e,i}, \delta_{z,i}) = \mathbb{E}_i \left[ -\exp \left\{ -\frac{(\mathbb{E}_i [F|s_i, P] - P)^2}{2\text{var}_i [F|s_i, P]} \right\} \right]. \quad (35)$$

Moreover, given the characterization of the equilibrium price in Lemma 1, investor  $i$ 's beliefs about the conditional return are given by:

$$\mathbb{E}_i [\mathbb{E}_i [F|s_i, P] - P] = m - m = 0, \text{ and} \quad (36)$$

$$\text{var}_i [\mathbb{E}_i [F|s_i, P] - P] = \text{var}_i [F - P] - \text{var}_i [F|s_i, P], \quad (37)$$

where the first equality follows from the law of iterated expectations and the second equality follows from the law of total variance.<sup>20</sup> With this in mind, the above expectation reduces to

$$AU_i(\delta_{e,i}, \delta_{z,i}) = -\sqrt{\frac{\text{var}_i [F|s_i, P]}{\text{var}_i [F - P]}}. \quad (39)$$

From this, we derive the following result.

**Lemma 3.** *Anticipated utility is always (weakly) increasing in  $\delta_{e,i}$ ; it is strictly increasing as long as  $\delta_{z,i} > 0$ . Anticipated utility is non-monotonic in  $\delta_{z,i}$ : there exists some  $\bar{\delta}$  such that for all  $\delta_{z,i} < \bar{\delta}$  anticipated utility is decreasing in  $\delta_{z,i}$  while for all  $\delta_{z,i} > \bar{\delta}$  it is increasing.*

To gain some intuition, we note that anticipated utility is simply a monotonic transformation of

$$\frac{\text{var}_i [F - P]}{\text{var}_i [F|s_i, P]} = \text{var}_i \left( \frac{\mathbb{E}_i [F - P|s_i, P]}{\sqrt{\text{var}_i [F - P|s_i, P]}} \right) \equiv \text{var}_i (SR_i) \quad (40)$$

where

$$SR_i \equiv \frac{\mathbb{E}_i [F - P|s_i, P]}{\sqrt{\text{var}_i [F - P|s_i, P]}} \quad (41)$$

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<sup>20</sup>The law of total variance implies

$$\text{var}_i [F - P] = \mathbb{E}_i [\text{var}_i [F - P|s_i, P]] + \text{var}_i [\mathbb{E}_i [F - P|s_i, P]], \quad (38)$$

which in turn, implies the above expression.

is investor  $i$ 's conditional Sharpe ratio, given her beliefs. When the variance of the conditional Sharpe ratio is higher, the investor expects to observe both (i) more profitable trading opportunities and (ii) the opportunity to trade more aggressively. Of course, she also faces an increased likelihood of facing the opposite scenario, but the benefit on the upside always outweighs the reduction in expected profits on the downside.<sup>21</sup> As a result, anticipated utility is higher when the variance in the conditional Sharpe ratio is higher.

Intuitively, reducing the perceived uncertainty (i.e.,  $\text{var}_i [F - P|s_i, P]$ ) about the trading opportunity is valuable - if the investor has better information about the value of the asset this increases her utility. Increasing the perceived precision of the private signal (i.e., increasing  $\delta_{e,i}$ ) has this effect and so anticipated utility increases when the investor inflates her perception of the quality of the private signal.

On the other hand, increasing the perceived precision of the price signal (i.e., increasing  $\delta_{z,i}$ ) has two off-setting effects. First, the **information effect** of learning from prices reduces the conditional variance  $\text{var}_i [F - P|s_i, P]$ : the investor has better information about the asset's value which increases anticipated utility. This information effect reduces the volatility of the perceived return on the risky security, a benefit in and of itself, but it also allows the investor to scale up her trading position. Second, the **speculative effect** of believing prices are more informative decreases the perceived variance of the conditional expected return (i.e.,  $\text{var}_i (\mathbb{E}_i [F|s_i, P] - P)$ ), which lowers anticipated utility. Intuitively, when the price is more informative, it tracks fundamentals more closely and, as a result, the trading opportunity is less profitable. The overall effect of changing the perceived precision of the price signal depends on the relative magnitude of these two effects. As we show in the proof of Lemma 3, the latter effect dominates when  $\delta_{z,i}$  is low, while the former effect dominates when  $\delta_{z,i}$  is sufficiently high, which is what drives the non-monotonicity in  $\delta_{z,i}$ .

This is the key distinction between learning from private signals and learning from price information and it drives our equilibrium results below. Learning from either source is informative about fundamentals which naturally increases utility. However, learning from prices also reduces the investor's perception of the potential trading opportunity. We explore how this distinction leads to differences in investors' subjective interpretation of private signals and the information in the price in the next two sections.

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<sup>21</sup>This arises because the trading opportunity and the investor's position act as complements - effectively, the utility is convex in the trading opportunity (as captured by the conditional Sharpe ratio), and so an increase in the perceived variance is beneficial.

## 6 Benchmark: Belief choice about private signals

We begin with a benchmark in which investors are forced to have objective beliefs about the price signal (i.e., we assume  $\delta_{z,i} = 1$  for all  $i$ ) but can choose their beliefs about the precision of their private signals. Unsurprisingly, given the intuition laid out above, we find that all investors choose to exhibit over-confidence about their private information in equilibrium.

**Proposition 1.** *Suppose investors have objective beliefs about the price signal i.e.,  $\delta_{z,i} = 1$  for all  $i$ , and the cost function  $C(\delta_{e,i}, \delta_{z,i})$  is well-behaved. Then, there exists a unique symmetric equilibrium in which all agents are over-confident about their private signal.*

With objective beliefs about the informativeness of the price, Lemma 3 implies that an investor's anticipated utility strictly increases in the perceived precision of her private signal. Since the cost of setting  $\delta_{e,i} = 1$  is zero (i.e.,  $C(1, 1) = 0$ ) and the marginal cost of increasing  $\delta_{e,i}$  at  $\delta_{e,i} = \delta_{z,i} = 1$  is also zero, investors prefer to optimally choose  $\delta_{e,i} > 1$  i.e., they optimally choose to be over-confident about her private signal.

**Proposition 2.** *Suppose investors have objective beliefs about the price signal i.e.,  $\delta_{z,i} = 1$  for all  $i$ , and face the experienced utility penalty, i.e., they solve (12). Then, there exists a unique equilibrium in which the optimal choice of  $\delta_{e,i} = \delta_e$  satisfies:*

$$\frac{(\tau + \tau_p + \tau_e \delta_e (2 - \delta_e))^{\frac{3}{2}}}{(\tau + \tau_p + \tau_e \delta_e)^{\frac{3}{2}}} = 2(\delta_e - 1). \quad (42)$$

Moreover, the equilibrium overconfidence parameter,  $\delta_e$ , (i) increases with  $\tau$  and  $\tau_z$ , (ii) decreases with risk-aversion  $\gamma$ , and (iii) is U-shaped in  $\tau_e$ .

Consistent with the intuition laid out above, equation (42) shows that in a symmetric equilibrium,  $\delta_{e,i} > 1$  for all agents.<sup>22</sup> What drives the degree of overconfidence? As prior uncertainty falls ( $\uparrow \tau$ ) and as the quality of the information in prices rises ( $\uparrow \tau_z, \downarrow \gamma$ ), both the benefit and cost of being overconfident falls: overconfidence is less distortive of the investor's perceived information advantage. Interestingly, as overconfidence grows, the cost falls more quickly, and so when investors have access to better outside information, overconfidence is higher.<sup>23</sup> While similar logic applies with respect to the quality of the investor's private signal, increasing overconfidence directly distorts how this information is utilized. As a result, for low values of  $\tau_e$  the benefit of increased overconfidence falls more quickly, which introduces a non-monotonicity in  $\delta_e$  as  $\tau_e$  increases.

<sup>22</sup>The LHS of (42) is always positive, which indicates that  $\delta_e > 1$ .

<sup>23</sup>This can be seen by evaluating the numerator of equation (42).

**Corollary 1.** *Relative to the rational expectations equilibrium (i.e., when  $\delta_{z,i} = \delta_{e,i} = 1$  for all  $i$ ), the equilibrium characterized in Proposition 1 features: (i) lower return volatility, (ii) a less negative predictability coefficient, (iii) higher price informativeness, and (iv) higher expected volume.*

These implications follow naturally from the expressions in 2 and noting the fact that because  $\delta_e > 1$ , the price sensitivity  $\Lambda$  in this equilibrium is higher than in the rational expectations equilibrium and both are higher than the signal to noise ratio i.e.,

$$\Lambda = \frac{\delta_e \tau_e + \tau_p}{\tau + \delta_e \tau_e + \tau_p} > \Lambda_{RE} = \frac{\tau_e + \tau_p}{\tau + \tau_e + \tau_p} > \kappa. \quad (43)$$

Our result on return predictability is consistent with Daniel et al. (1998), who argue that investor overconfidence results in price reversals. Moreover, overconfidence induces investors to trade more aggressively based on their signals. This results in more informative prices, which is consistent with the empirical evidence discussed in Hirshleifer, Subrahmanyam, and Titman (1994); Kyle and Wang (1997); Odean (1998b); Hirshleifer and Luo (2001). Finally, consistent with the large literature on overconfidence, our model suggests that such behavior by investors can help explain the relatively high trading volume that has been extensively documented empirically.

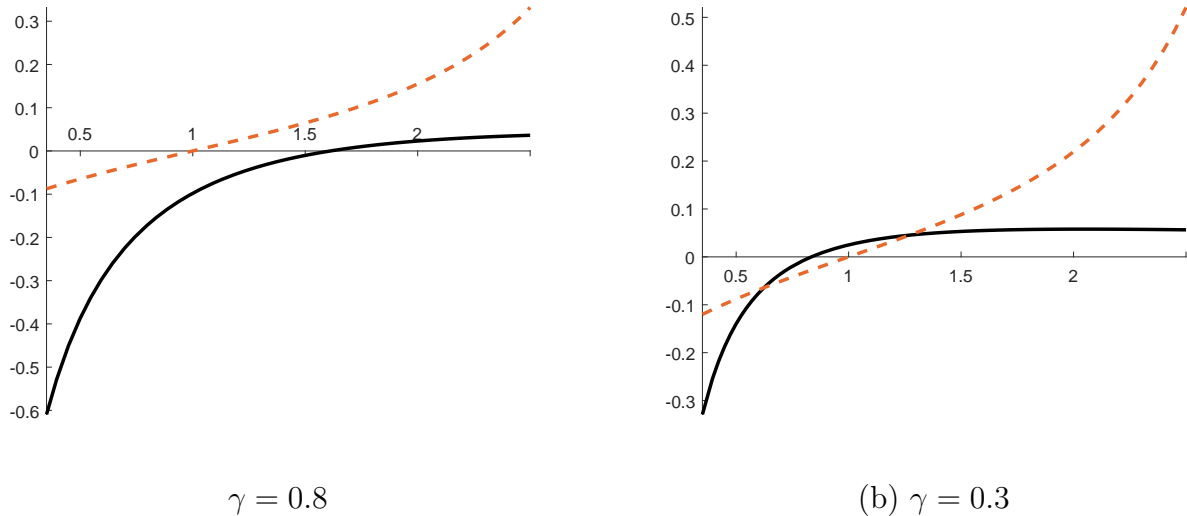
## 7 Belief choices and equilibrium characterization

We now turn to the more general setting in which investors can optimally choose their beliefs about both the quality of their private signal as well as the information contained in prices. We begin by characterizing the characteristics of any feasible symmetric equilibrium.

**Proposition 3.** *Suppose the cost function  $C(\delta_{e,i}, \delta_{z,i})$  is well-behaved. In any symmetric equilibrium, all investors are (weakly) over-confident about their private signal (i.e.,  $\delta_{e,i} \geq 1$  for all  $i$ ) but choose to under-react to the information in prices (i.e.,  $\delta_{z,i} < 1$  for all  $i$ ).*

Thus, in any symmetric equilibrium, investors always choose to over-confident about their private information (as above) but under-react to the information in prices. This is a robust outcome in our setting. Consider the choices  $\delta_{e,i}$  and  $\delta_{z,i}$  of investor  $i$  in a symmetric equilibrium where all other investors choose  $\delta_e$  and  $\delta_z$ , respectively. Recall that for a well-behaved cost function, deviations away from rational expectations (i.e.,  $\delta_{e,i} = 1$  and  $\delta_{z,i} = 1$ ) are penalized i.e., the cost function is decreasing below one and increasing above one. Since anticipated utility is always (weakly) increasing in  $\delta_{e,i}$ , this immediately implies any symmetric equilibrium features (weak) over-confidence about private information

Figure 1: Marginal Anticipated Utility vs. Marginal Cost for the experienced utility penalty. The figure shows marginal anticipated utility (solid black line) and marginal cost function (dashed orange line) as a function of  $\delta_{z,i}$ . The marginal cost function is under the assumption that investors incur the experienced utility penalty (i.e., their beliefs satisfy (12)). Other parameters are:  $\tau = \tau_e = \tau_z = \delta_e = \delta_{e,i} = 1$ ,  $\delta_z = 0.5$ .



(i.e.,  $\delta_{e,i} \geq 1$ ). Intuitively, increasing the perceived precision of private information always increases anticipated utility, and so it is natural that investors choose to be over-confident about their private signals.

However, as Lemma 3 establishes, anticipated utility is U-shaped in  $\delta_{z,i}$ . Moreover, as we show in the proof of Proposition 3, when other investors choose  $\delta_z$ , anticipated utility is decreasing in  $\delta_{z,i}$  at  $\delta_{z,i} = \delta_z$ . This implies the equilibrium choice of  $\delta_{z,i}$  cannot be higher than one, since if this were the case, investor  $i$  could increase her anticipated utility and decrease her costs by reducing  $\delta_{z,i}$ , an unambiguously better outcome. Intuitively, in a symmetric equilibrium, investor  $i$  has an incentive to decrease the perceived precision of price information relative to the choice of others because by doing so, she improves her ability to speculate on her private information by decreasing the correlation between her conditional valuation ( $\mu_i$ ) and those of other investors (i.e.,  $\int_j \mu_j dj$ ), which is reflected in the equilibrium price.

Given the above characterization for arbitrary cost functions, the next subsections characterize conditions for the existence of symmetric equilibria for the experienced utility penalty benchmark.

## 7.1 Symmetric equilibrium and under-reaction to prices

We begin with a sufficient condition for the existence and uniqueness of symmetric equilibria.

**Proposition 4.** *Suppose investors incur the experienced utility penalty i.e., their beliefs satisfy (12). There exists a  $\bar{\gamma}$  such that for all  $\gamma \geq \bar{\gamma}$ , there exists a unique, symmetric equilibrium in which all investors ignore the information in prices (i.e.,  $\delta_{z,i} = 0$  for all  $i$ ), and correctly interpret their private signals (i.e.,  $\delta_{e,i} = 1$  for all  $i$ ).*

The plot in Figure 1, panel (a), provides a numerical illustration. The figure plots the marginal anticipated utility (solid) and the marginal cost function (dashed) for an investor  $i$  as a function of her choice  $\delta_{z,i}$ . Recall that deviations away from  $\delta_{z,i}$  are costly — as a result, the marginal cost for  $\delta_{z,i} < 1$  is negative. Moreover, note that Lemma 3 implies that the marginal anticipated utility is negative below a threshold  $\bar{\delta}$  (which is a little above 1.5 in the plot). Finally, note that while the marginal anticipated utility when  $\delta_{z,i} = 0$  is  $-\infty$ , the marginal cost in this case is always negative but *finite*. At any alternative symmetric equilibrium the marginal benefit and marginal cost must intersect.<sup>24</sup> A sufficiently high  $\gamma$  ensures that (i) the marginal anticipated utility curve intersects zero at a point to the right of  $\delta_{z,i} = 1$ , and (ii) the marginal cost curve is sufficiently flat between  $\delta_{z,i} = 0$  and  $\delta_{z,i} = 1$ . This in turn ensures that the two curves never intersect, and the symmetric equilibrium is a corner solution at  $\delta_{z,i} = 0$ .

Intuitively, when  $\gamma$  is high, price informativeness  $\tau_p$  is relatively low. In this case, the speculative effect of learning from prices dominates the information effect, and investors prefer to under-weight the information in prices. When  $\gamma$  is sufficiently high, the price is sufficiently uninformative, and investors optimally choose to ignore the information in prices. Since the marginal anticipated utility does not change with  $\delta_{e,i}$  when  $\delta_{z,i} = 0$ , investors optimally choose to correctly interpret their private information (i.e.,  $\delta_{e,i} = 1$ ).

## 7.2 Asymmetric equilibrium and specialization of beliefs

The next result establishes sufficient conditions to rule out the existence of a symmetric equilibrium.

**Proposition 5.** *Suppose investors incur the experienced utility penalty, i.e., their beliefs satisfy (12). There exists a  $\underline{\gamma}$  such that for all  $\gamma < \underline{\gamma}$ , there cannot exist a symmetric equilibrium.*

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<sup>24</sup>Specifically, any other potential maximum lies at every second intersection of the two curves.

Again, consider the numerical example plotted in Figure 1, panel (b). When  $\gamma$  is sufficiently low, the marginal anticipated utility curve crosses zero below  $\delta_{z,i} = 1$ . This implies that there is always a (local) maximum, corresponding to the second intersection of the solid and dotted lines. Investor  $i$  might prefer to deviate from the corner ( $\delta_{z,i} = 0$ ) to this interior maximum, if her expected anticipated utility, net of cost, is higher.

Intuitively, this can occur when  $\gamma$  is sufficiently low because price informativeness is sufficiently high (investors trade more aggressively on their information). Moreover, in any symmetric equilibrium, investors under-react to the information in prices. Together, these imply that an individual investor may have an incentive to deviate and condition *more* aggressively on the information in prices — in such a case, the speculative effect is dominated by the information effect. But such profitable deviations rule out a symmetric equilibrium.

The plots in Figure 2 provide a numerical example. The panels show investor  $i$ 's anticipated utility, net of costs, as a function of  $\delta_{z,i}$ , given the behavior of others. In panel (a), all other investors choose  $\delta_z = 0$ . In this case, investor  $i$  has an incentive to deviate by over-weighting the information in prices (i.e., by setting  $\delta_{zi} \approx 1.3$ ). Even though the price is objectively very informative (large information effect), because other investors are ignoring it ( $\delta_z = 0$ ), the speculative effect of overweighting the price is relatively small. In panel (b), we consider an alternative symmetric equilibrium in which all other investors choose  $\delta_z > 0$ . Now, the speculative effect dominates and investor  $i$  strictly prefers to ignore the information in prices. In both cases, a symmetric equilibrium is ruled out because an individual investor has an incentive to deviate from the equilibrium behavior.

Given the non-existence of symmetric equilibria, we numerically explore the existence of asymmetric equilibria in which investors mix between two sets of beliefs. We assume a fraction  $\lambda$  optimally chooses  $\delta_{e,i} = 1$  and  $\delta_{z,i} = 0$ , while the remaining fraction  $1 - \lambda$  optimally chooses  $\delta_{e,i} = \delta_e$  and  $\delta_{z,i} = \delta_z$ . The following result characterizes the existence of such an equilibrium.

**Lemma 4.** *An asymmetric equilibrium is characterized by the triple  $(\lambda, \delta_e, \delta_z)$  which solve a system of three equations (specified in the Appendix). The equilibrium price is given by:*

$$P = m + \Lambda_{AE}(s_p - m), \text{ where } s_p = F - \frac{\gamma}{\delta_e \tau_e} z,$$

$$\Lambda_{AE} \equiv \frac{\bar{\delta}_e \tau_e + \bar{\delta}_z \tau_{p,AE}}{\tau + \bar{\delta}_e \tau_e + \bar{\delta}_z \tau_{p,AE}}, \quad \tau_{p,AE} = \frac{\tau_z \tau_e^2 \bar{\delta}_e^2}{\gamma^2}, \quad (44)$$

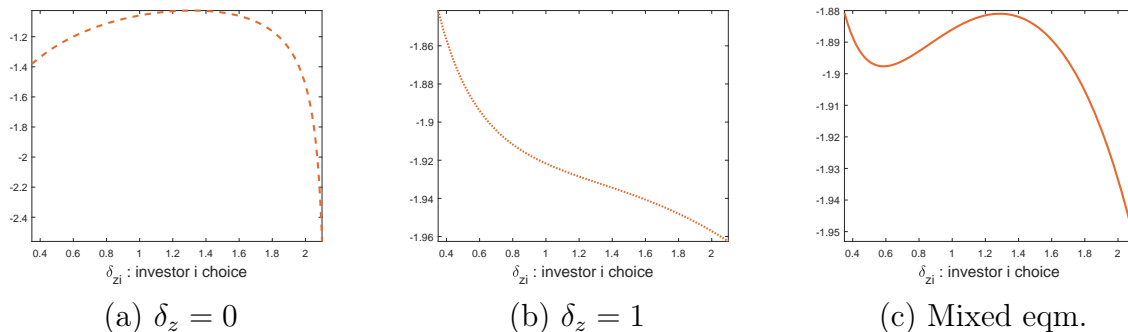
$\bar{\delta}_e = (\lambda + (1 - \lambda) \delta_e)$  and  $\bar{\delta}_z = (1 - \lambda) \delta_z$ . Moreover,  $\delta_e, \delta_z \leq 3/2$ , and  $\Lambda_{AE} < \Lambda_{RE} = \frac{\tau_e + \tau_p}{\tau + \tau_e + \tau_p}$  under some conditions reported in the appendix.

Panel (c) of Figure 2 illustrates an instance of the asymmetric equilibrium. In this case,



Figure 2: Anticipated utility net of costs versus  $\delta_{z,i}$

The figure plots the anticipated utility net of costs for investor  $i$  as a function of her choice  $\delta_{z,i}$ . Other parameters are:  $\tau = \tau_e = \tau_z = \delta_e = \delta_{e,i} = 1$ ,  $\gamma = 0.3$



each investor is indifferent between two (sets of) beliefs. In equilibrium, one set of investors (a fraction  $\lambda = 0.95$ ) ignore the information in prices while the remaining fraction  $1 - \lambda = 0.05$  overweight the information in prices.

## 8 Empirical Implications

This section compares return-volume characteristics of the symmetric and asymmetric equilibria to the rational expectations benchmark. We begin with a comparison of the symmetric equilibrium characterized in Proposition 4.

**Corollary 2.** *Relative to the rational expectations equilibrium (i.e., when  $\delta_{z,i} = \delta_{e,i} = 1$  for all  $i$ ), the equilibrium characterized in Proposition 4 features: (i) higher predictability coefficient, (ii) equal price informativeness, and (iii) equal expected volume. Return volatility is higher than in the rational expectations equilibrium iff price informativeness is sufficiently high (i.e.,  $\tau_p \geq \frac{\sqrt{\tau^2 + 8\tau\tau_e + 8\tau_e^2}}{2} - \frac{\tau}{2}$ ).*

Since  $\delta_e = 1$  in the symmetric equilibrium, the signal to noise ratio  $\kappa$  is the same as in the rational expectations equilibrium (since  $\beta = -\gamma/\tau_e$ ). However, the price sensitivity in the symmetric equilibrium,  $\Lambda_{SE} = \frac{\tau_e}{\tau + \tau_e}$ , is lower than that in the rational expectations equilibrium (i.e.,  $\Lambda_{RE} = \frac{\tau_e + \tau_p}{\tau + \tau_e + \tau_p}$ ). Following the discussion of Lemma 2, this immediately implies the results on the predictability coefficient and price informativeness. The volume remains the same across the two symmetric equilibria since the investors weight their private signals correctly (i.e.,  $\delta_{ei} = 1$ ) in either case. This implies that the cross-sectional variation in valuations, scaled by their posterior variance, remains unaffected by whether or not they

condition on prices.<sup>25</sup> Finally, we characterize conditions under which return volatility is higher under the subjective beliefs equilibrium. Recall that return volatility is decreasing in  $\Lambda$  when the signal to noise ratio  $\kappa = \frac{\tau_p}{\tau + \tau_p}$  is sufficiently high (relative to  $\Lambda$ ). The condition on  $\tau_p$  above ensures that the decrease in  $\Lambda$  (from  $\Lambda_{RE}$  to  $\Lambda_{SE}$ ) leads to an increase in volatility.

As the next result highlights, the asymmetric equilibrium has distinct predictions for price informativeness and trading volume.

**Corollary 3.** *Relative to the rational expectations equilibrium (i.e., when  $\delta_{z,i} = \delta_{e,i} = 1$  for all  $i$ ), the equilibrium characterized in Proposition 5 features: (i) higher predictability coefficient, (ii) higher price informativeness, and (iii) higher expected volume.*

The asymmetric equilibrium has three main implications. First, the return predictability coefficient is higher than in an rational expectations equilibrium and can even be positive. In the traditional noisy-rational expectations setting with exogenous, transient noise trading (e.g., Hellwig (1980)), returns exhibit reversals. Intuitively, an aggregate demand (supply) shock temporarily pushes the current price up (down, respectively), but since the shock is not persistent, prices revert in the future. In our model, because some investors underweight the information in prices, prices do not adjust to their informationally efficient levels and there is residual (positive) predictability in returns. This mechanism is similar to the one found in Hong and Stein (1999) and Banerjee et al. (2009).

Second, we show that price informativeness is higher in this equilibrium compared to a standard REE model. In our model, price informativeness increases with the weight investors place on private signals. Since in an asymmetric equilibrium, a fraction of agents place strictly higher weight than in a rational expectations model (and all others objectively weight their private information), the model features higher price informativeness than if all investors held rational expectations. This result is consistent with empirical evidence discussed in Hirshleifer et al. (1994); Hirshleifer and Luo (2001).

Third, volume in an asymmetric equilibrium is higher than in the corresponding REE model. In an asymmetric equilibrium, in addition to volume generated by cross-sectional variation in private signals, there is additional trade between the different groups of investors. This latter source of additional volume is absent in both the rational expectations and the symmetric, subjective beliefs equilibria.

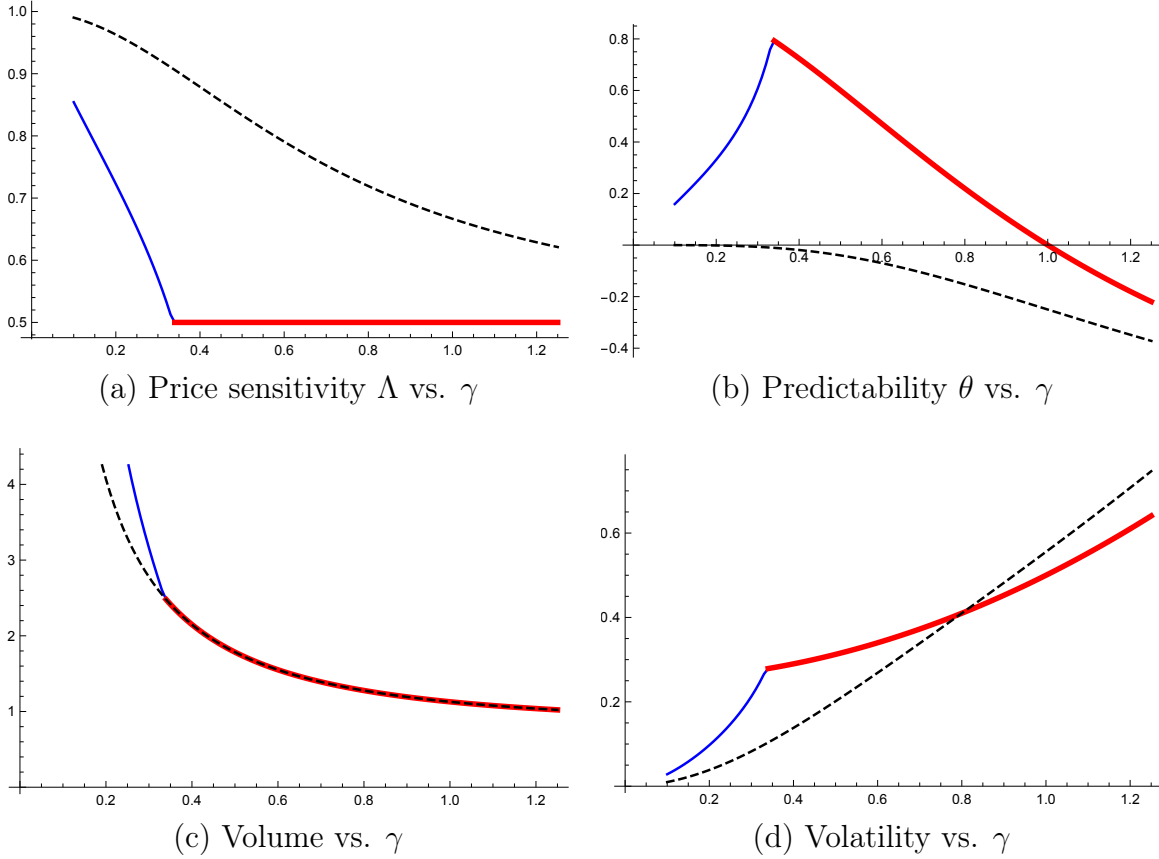
Figure 3 provides a numerical illustration of these results. Specifically, the figure plots price sensitivity, predictability, volume and volatility for the rational expectations (dashed) and subjective beliefs equilibria (solid) as a function of risk aversion  $\gamma$ . Moreover, the kink

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<sup>25</sup>This is apparent in the limit when there is no private information i.e.,  $\tau_e = 0$ . In this case, volume is zero in any symmetric equilibrium, irrespective of whether investors condition on prices or not.

Figure 3: Comparison of return and volume characteristics

The figure plots price sensitivity, return predictability, trading volume and return volatility (variance) as a function of risk aversion for subjective beliefs (solid line) and rational expectations (dotted line). Other parameters are set to  $\tau = \tau_e = \tau_z = 1$ . The thin (blue) part of the solid line corresponds to the asymmetric equilibrium, while the thick (red) part corresponds to the symmetric equilibrium.



in the solid lines corresponds to the value of  $\gamma$  at which the subjective beliefs equilibrium switches from the asymmetric equilibrium (low  $\gamma$ ) to the symmetric equilibrium (higher  $\gamma$ ). Consistent with the predictions of Corollaries 2 and 3, predictability and volume are (weakly) higher under subjective beliefs than under rational expectations. Moreover, volatility is higher under subjective beliefs when risk aversion is sufficiently low (i.e.,  $\tau_p$  is sufficiently high), but is higher otherwise. Finally, in this parameter region, the price sensitivity  $\Lambda$  is always lower for the subjective beliefs equilibrium.

## 9 Welfare

In this section, we explore the welfare implications of allowing investors to choose their beliefs optimally. We begin by noting that welfare for the informed investors depends on the reference beliefs used. From the perspective of the investors' subjective beliefs, expected utility is higher when they deviate from rational expectations. However, from the perspective of a social planner who is restricted to hold objective beliefs, expected utility for informed investors is strictly lower when they deviate from rational expectations - their demand for the risky asset is suboptimal given their information sets.

For our welfare analysis below, we use the objective distribution as the reference beliefs and define expected utility for an informed investor as

$$U_i \equiv \mathbb{E} \left[ -\exp \left\{ -\gamma x_i^* (\delta_{e,i}^*, \delta_{z,i}^*) \times (F - P) - \gamma W_0 \right\} \right], \quad (45)$$

where  $x_i^* (\delta_{e,i}^*, \delta_{z,i}^*)$  is her optimal demand under her optimally chosen beliefs  $\delta_{e,i}^*, \delta_{z,i}^*$ . Note that this is a conservative measure of expected utility as it only accounts for the costs of deviating from rational expectations and does not include any of the gains from anticipated utility.

We can also consider the effect of informed investors' deviations from rational expectations on the welfare of liquidity (or noise) traders. Recall that the aggregate supply,  $z$ , is noisy. Suppose this reflects the sale of the risky asset by a liquidity trader, who has CARA utility with risk aversion  $\gamma_z$  and is endowed with initial wealth  $W_0$ . Then, her expected utility is given by

$$U_z \equiv \mathbb{E} \left[ -\exp \left\{ -\gamma_z (-z) \times (F - P) - \gamma_z W_0 \right\} \right]. \quad (46)$$

The following result compares the expected utility of liquidity traders and the overall welfare in the constrained and unconstrained equilibria.

**Proposition 6.** *In equilibrium, the expected utility of a liquidity trader is given by:*

$$U_z = -\sqrt{\frac{\tau_z}{\tau_z + 2\gamma_z \left( \beta\Lambda - \frac{1}{2\tau} \gamma_z (1-\Lambda)^2 \right)}} \exp \left\{ -\gamma_z W_0 \right\} \quad (47)$$

Suppose  $\gamma_z \leq \gamma$ . Then:

(i) *Liquidity traders have higher expected utility in the symmetric equilibrium than in the rational expectations equilibrium.*

(ii) *In any asymmetric equilibrium in which  $\Lambda_{AE} < \Lambda_{RE}$ , liquidity traders have higher expected utility in the asymmetric equilibrium than in the rational expectations equilibrium.*

(iii) *There exists  $\underline{\gamma} \geq 0$  such that for all  $\gamma \geq \underline{\gamma}$ , total welfare is higher under the subjective*

beliefs equilibrium than under the rational expectations equilibrium.

Expected utility for a liquidity trader depends on the equilibrium parameters through a term

$$\beta\Lambda - \frac{1}{2\tau}\gamma_z(1-\Lambda)^2. \quad (48)$$

To gain some intuition for this expression, it is illustrative to consider the (conditional) expected utility of the liquidity trader if she had mean-variance preferences.<sup>26</sup> Selling  $z$  units gives her utility  $u(z)$ , where

$$u(z) = -z\mathbb{E}[F - P|z] - \frac{1}{2}\gamma_z z^2 \text{var}(F - P|z) \quad (50)$$

$$= \beta\Lambda z^2 - \frac{1}{2}\gamma_z z^2 (1-\Lambda)^2 \frac{1}{\tau}, \quad (51)$$

where  $\beta = -\frac{\gamma}{\tau_e \delta_e} < 0$ . Therefore, a liquidity trader's utility is driven by two components. The first component ( $\beta\Lambda z^2$ ) reflects her disutility from price impact — for instance, a larger sale (higher  $z$ ) pushes prices downward, which reduces her proceeds. The second term ( $-\frac{1}{2}\gamma_z z^2 (1-\Lambda)^2 \frac{1}{\tau}$ ) reflects a standard risk-aversion channel — when prices are less informative about fundamentals, the liquidity trader faces more uncertainty about her payoff, which reduces utility. It is important to note that expected utility is finite only when

$$\tau_z + 2\gamma_z (\beta\Lambda - \frac{1}{2\tau}\gamma_z(1-\Lambda)^2) > 0. \quad (52)$$

Intuitively, if the combined disutility from the price impact and risk aversion terms are too large, the liquidity trader's expected utility from being forced to trade  $z$  units approaches negative infinity — she would rather exit the market and not trade if she could.<sup>27</sup>

The proposition characterizes conditions under which liquidity traders are better off when informed investors choose their beliefs. As discussed earlier, price sensitivity,  $\Lambda$ , is higher when investors exhibit rational expectations:  $\Lambda_{RE} > \Lambda_{SE}, \Lambda_{AE}$ . This has offsetting effects on the liquidity trader's utility. On the one hand, a higher  $\Lambda$  implies that the price is more sensitive to her trade and so utility falls through the price impact channel. On the other hand, a higher  $\Lambda$  implies prices track fundamentals more closely which reduces the risk in the liquidity trader's payoff. As we show in the proof of Proposition 6, the price impact

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<sup>26</sup>Note that by the Law of Iterated Expectations, we have:

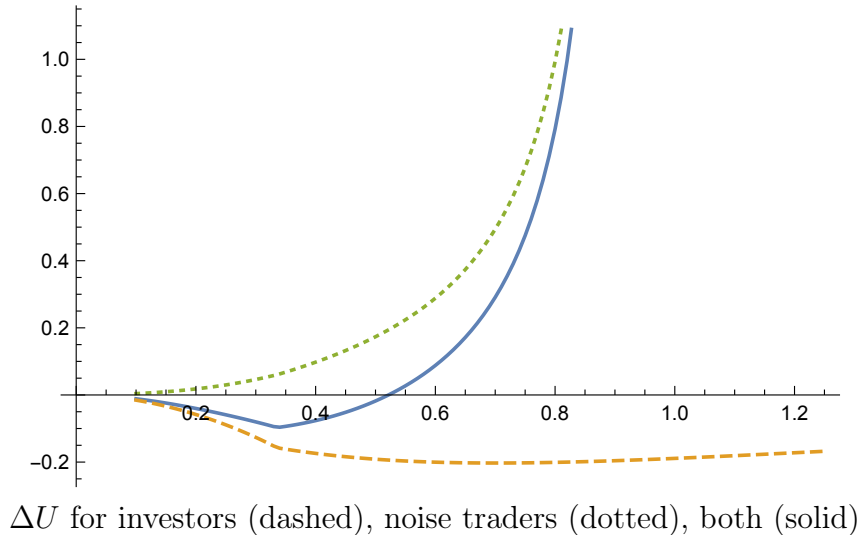
$$U_z \propto \mathbb{E}[\mathbb{E}[-\gamma \exp\{-\gamma(-x(F-P))\} | z]] = \mathbb{E}[-\exp\{-\gamma u(z)\}], \quad (49)$$

so considering mean-variance preferences is qualitatively without loss of generality.

<sup>27</sup>This highlights a limitation of assuming that liquidity traders submit price insensitive orders. An alternative approach would be to model liquidity shocks as hedging demands for the informed investors. However, this makes the analysis less tractable and the intuition for the results in the rest of the paper less clear.

Figure 4: Difference in expected utility  $U_{OE} - U_{RE}$  versus  $\gamma$

The figure plots the difference in utility across the subjective beliefs and rational expectations equilibria. The dashed line plots the difference in expected utility of informed investors (under the objective distribution) (i.e.,  $U_{i,OE} - U_{i,RE}$ ), the dotted line plots the difference in expected utility for the noise traders (i.e.,  $U_{z,OE} - U_{z,RE}$ ), and the solid line plots the difference in utility across both groups (i.e.,  $U_{i,OE} + U_{z,OE} - (U_{i,RE} + U_{z,RE})$ ). Other parameters are set to  $\tau = \tau_e = \tau_z = 1$ , and  $\gamma_z = 0.75$ .



effect always dominates the risk-aversion effect if the risk aversion of the investors is weakly higher than that of the liquidity traders (i.e.,  $\gamma_z \leq \gamma$ ). In this case, liquidity traders are always better off when informed investors choose to deviate from rational expectations.

Note that  $\gamma_z \leq \gamma$  is a sufficient condition, but it is not necessary for liquidity traders to be better off under the subjective beliefs equilibrium. Figure 4 plots the difference in expected utility between the subjective beliefs equilibrium and the rational expectations equilibrium as a function of investor risk aversion  $\gamma$  for each group separately, and for both groups as a whole. The plot illustrates that for this set of parameters, liquidity traders are always better off under subjective beliefs — the dotted line is always above zero — irrespective of whether informed investors are more or less risk averse than them. In particular, note that noise trader risk aversion  $\gamma_z$  is fixed at 0.75, but informed investor risk aversion  $\gamma$  ranges from 0.1 to 1.2. Moreover, under the objective distribution, the informed investors are worse off under the subjective beliefs equilibrium — the dashed line is always below zero.

The solid line in Figure 4 illustrates the aggregate welfare ranking in Proposition 6. Specifically, aggregate welfare appears to be higher in the rational expectations equilibrium when informed investor risk aversion is low, but higher under subjective beliefs when risk aversion is high. First, when risk aversion is low, price impact is low, and so the relative

benefit to noise traders in the subjective beliefs equilibrium is low. Second, when risk aversion is low, informed investors trade more aggressively on their distorted beliefs, and this decreases their expected utility more.

In contrast, when risk aversion is sufficiently high, the benefit to noise traders is larger (due to higher price impact). Moreover, when risk aversion is sufficiently high, price informativeness is low and investors trade less aggressively, which imply that the relative cost of distorted beliefs in the subjective beliefs equilibrium is lower (the dashed line is eventually increasing in  $\gamma$ ). As a result, when risk aversion is high, welfare is higher under subjective beliefs.

Our results suggest that while deviations from rational expectations are arguably costly for informed investors, they may make liquidity traders better off. Moreover, our welfare results do not account for changes in the real (allocative) efficiency. Since price informativeness is higher when informed investors deviate from rational expectations, the real efficiency in the economy can also be higher under such deviations if investment / allocative decisions are made on the information in prices.

## 10 Extensions and concluding remarks

In this paper, we analyze how investors who experience anticipated utility optimally choose their subjective beliefs about their informational environment in the context of an otherwise standard competitive trading environment. We show that in any symmetric equilibrium, investors are always (i) weakly overconfident in the quality of their private signal (so that their perceived private information advantage is preserved or amplified), and (ii) discount the quality of the information in prices (so that their perceived trading opportunity is maximized).

We have also shown that similar results arise in related settings. In a setting without aggregate noise, investors still choose to underweight the information in prices but overweight their private information.<sup>28</sup> In this case, the price provides a perfectly revealing signal about the fundamental  $F$ ; however, we show that investors still choose to partially dismiss this information in any symmetric equilibrium.

In Appendix B.2, we explore how, in addition to the choices made in the benchmark model, investors would choose to interpret the informativeness of a public signal. We show that, like the price, an increase in the perceived precision of the public signal increases

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<sup>28</sup>As we discussed in Section 3.1, we consider a setting in Appendix B.1 where investors have subjective beliefs about the variance and correlation in errors of others' signals. In this setting, we can show that overconfidence and dismissiveness obtain even when we assume the aggregate supply of the asset is commonly known to be  $z = 0$ .

anticipated utility through the information channel, but reduces it through the speculative channel. However, in contrast to the information in prices, we show that the informational channel dominates the speculative channel in any symmetric equilibrium. As a result, we find that investors tend to over-weight the information in public signals.

Our analysis suggests that allowing for subjective belief choice is likely to be a fruitful approach to understanding individual behavior in strategic settings. In a financial market setting, we show that common behavioral biases such as overconfidence and dismissiveness arise naturally as outcomes of belief choice. Moreover, as highlighted by our asymmetric equilibrium, this approach can give rise to endogenous heterogeneity in investor behavior. While a financial market is characterized by strategic substitutability, other strategic settings feature complementarity (e.g., beauty contest games, coordination games). In future work, we hope to explore the implications of subjective belief choice in these settings. Taken together, these results may help us better understand why different biases arise in different environments.



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# A Proofs

## A.1 Proof of Lemma 3

Lemma 1 implies that the price is of the form:  $P = m + \Lambda (s_p - m)$ . This implies anticipated utility is given by

$$AU(\delta_{e,i}, \delta_{z,i}) = -\sqrt{\frac{\frac{1}{\tau + \delta_{e,i}\tau_e + \delta_{z,i}\tau_p}}{(1-\Lambda)^2 \frac{1}{\tau} + \Lambda^2 \frac{1}{\delta_{z,i}\tau_p}}}. \quad (53)$$

Note that given other investors' choices, investor  $i$ 's marginal anticipated utility is

$$\frac{\partial}{\partial \delta_{e,i}} AU = \frac{\tau_e}{2(\tau + \delta_{e,i}\tau_e + \delta_{z,i}\tau_p)} \times \sqrt{\frac{\frac{1}{\tau + \delta_{e,i}\tau_e + \delta_{z,i}\tau_p}}{(1-\Lambda)^2 \frac{1}{\tau} + \Lambda^2 \frac{1}{\delta_{z,i}\tau_p}}} \geq 0 \quad (54)$$

$$\frac{\partial}{\partial \delta_{z,i}} AU = \frac{(1-\Lambda)^2 \delta_{z,i}^2 \tau_p^2 - \Lambda^2 \tau (\delta_{e,i}\tau_e + \tau)}{2\delta_{z,i} (\Lambda^2 \tau + (1-\Lambda)^2 \delta_{z,i}\tau_p) (\delta_{e,i}\tau_e + \delta_{z,i}\tau_p + \tau)} \times \sqrt{\frac{\frac{1}{\tau + \delta_{e,i}\tau_e + \delta_{z,i}\tau_p}}{(1-\Lambda)^2 \frac{1}{\tau} + \Lambda^2 \frac{1}{\delta_{z,i}\tau_p}}} \quad (55)$$

This implies anticipated utility is always increasing in  $\delta_{e,i}$ , and increasing in  $\delta_{z,i}$  when

$$\frac{\delta_{z,i}^2}{\delta_{e,i}\tau_e + \tau} > \frac{\Lambda^2}{(1-\Lambda)^2} \frac{\tau}{\tau_p^2}, \quad (56)$$

i.e., it is initially decreasing and then increasing in  $\delta_{z,i}$ . Moreover, note that

$$\lim_{\delta_{z,i} \rightarrow 0} \frac{\partial}{\partial \delta_{z,i}} AU = -\infty, \quad \lim_{\delta_{z,i} \rightarrow 0} \frac{\partial}{\partial \delta_{z,i}} AU = 0 \quad (57)$$

and  $\frac{\partial}{\partial \delta_{z,i}} AU$  equals zero at:

$$\delta_{z,i}^* = \frac{1}{\tau_p} \left( \frac{\Lambda}{1-\Lambda} \right) \sqrt{\tau (\delta_{e,i}\tau_e + \tau)} \quad (58)$$

□

## A.2 Proof of Proposition 1

The objective of investor  $i$  given by

$$\max_{\delta_{ei}} AU_i(\delta_{ei}) - C(\delta_{ei}).$$

Lemma 3 implies that anticipated utility increases with overconfidence parameter  $\delta_{ei}$ . So, investor tries to balance the benefit of increasing  $\delta_{ei}$  with the cost of increasing  $\delta_{ei}$ . The FOC with respect to  $\delta_{ei}$  is

$$\frac{\tau_e}{2 \left( \frac{(1-\Lambda)^2}{\tau_0} + \frac{\Lambda^2}{\tau_p} \right)^{\frac{1}{2}} (\tau_e \delta_{ei} + \tau_p + \tau_0)^{\frac{3}{2}}} = \frac{\partial C}{\partial \delta_{ei}} \quad (59)$$

and the second order condition is

$$-\frac{3\tau_e^2}{4 \left( \frac{(1-\Lambda)^2}{\tau_0} + \frac{\Lambda^2}{\tau_p} \right)^{\frac{1}{2}} (\tau_e \delta_{ei} + \tau_p + \tau_0)^{\frac{5}{2}}} - \frac{\partial^2 C}{\partial \delta_{ei}^2} < 0.$$

Condition (59) implies that the optimal overconfidence parameter is always greater than one i.e.,  $\delta_e^* \geq 1$ .  $\square$

### A.3 Proof of Proposition 2

Substituting  $\delta_{zi} = 1$  in equation 62, the cost function in this case is given by

$$C(\delta_{ei}) = \frac{1}{\sqrt{\left( \frac{(1-\Lambda)^2}{\tau_0} + \frac{\Lambda^2}{\tau_p} \right) (\tau_0 + \tau_p + \tau_e \delta_{ei} (2 - \delta_{ei}))}}$$

The FOC in the case of experienced utility penalty is given by

$$\frac{\tau_e}{2 \left( \frac{(1-\Lambda)^2}{\tau_0} + \frac{\Lambda^2}{\tau_p} \right)^{\frac{1}{2}} (\tau_e \delta_{ei} + \tau_p + \tau_0)^{\frac{3}{2}}} = \frac{\tau_e (\delta_{ei} - 1)}{\left( \frac{(1-\Lambda)^2}{\tau_0} + \frac{\Lambda^2}{\tau_p} \right)^{\frac{1}{2}} [(\tau_0 + \tau_p + \tau_e \delta_{ei} (2 - \delta_{ei}))]^{\frac{3}{2}}} \quad (60)$$

which simplifies to

$$\frac{(\tau_0 + \tau_p + \tau_e \delta_{ei} (2 - \delta_{ei}))^{\frac{3}{2}}}{(\tau_p + \tau_0 + \tau_e \delta_{ei})^{\frac{3}{2}}} = 2(\delta_{ei} - 1) \quad (61)$$

which establishes the result.  $\square$

**Lemma 5.** *With experienced utility penalty, the cost function is the disutility that the investor incurs under the objective distribution and is given by*

$$C(\delta_{ei}, \delta_{zi}) = \frac{1}{\sqrt{\Lambda^2 (\delta_{zi} - 1)^2 + \text{var}(F - P) (\tau + \tau_e \delta_{ei} (2 - \delta_{ei}) + \tau_p \delta_{zi} (2 - \delta_{zi}))}}. \quad (62)$$

*Proof.* Based on definition 2 and ignoring the second term (which is constant), the cost

function is

$$\begin{aligned} C(\delta_{ei}, \delta_{zi}) &= -\mathbb{E}[-\gamma \exp\{-\gamma x_i^* (\delta_{e,i}, \delta_{z,i}) \times (F - P) - \gamma W_0\}] \\ &= \mathbb{E}[\gamma \exp\{-\omega_i (\mu_i - P) \times (F - P)\}] \end{aligned}$$

Suppose we have:

$$\begin{pmatrix} \mu_i - P \\ F - P \end{pmatrix} \sim N \left( \begin{pmatrix} m_i \\ m \end{pmatrix}, \begin{pmatrix} \sigma_{ERi}^2 & \sigma_{ERi,ER} \\ \sigma_{ERi,ER} & \sigma_{ER}^2 \end{pmatrix} \right). \quad (63)$$

In this case, the cost function is given by

$$C(\delta_{ei}, \delta_{zi}) = \sqrt{\frac{\omega_i^{-2}}{(\omega_i^{-1} + \sigma_{ERi,ER})^2 - \sigma_{ER}^2 \sigma_{ERi}^2}}. \quad (64)$$

Note that

$$\begin{aligned} \sigma_{ER,i}^2 &= \text{var}(\mu_i - P) \\ &= \text{var}(A_i(s_i - m) + B_i(s_p - m) - \Lambda(s_p - m)) \\ &= \frac{(A_i + B_i - \Lambda)^2}{\tau} + \frac{A_i^2}{\tau_e} + \frac{(B_i - \Lambda)^2}{\tau_p} \end{aligned}$$

$$\sigma_{ER}^2 = \text{var}(F - P) = \frac{(1-\Lambda)^2}{\tau} + \frac{\Lambda^2}{\tau_p}$$

$$\begin{aligned} \sigma_{ERi,ER} &= \text{cov}(\mu_i - P, F - P) \\ &= \text{cov}(A_i s_i + B_i s_p - \Lambda s_p, F - \Lambda s_p) \\ &= \frac{(A_i + B_i - \Lambda)(1 - \Lambda)}{\tau} - \frac{(B_i - \Lambda)\Lambda}{\tau_p}. \end{aligned}$$

Substituting these coefficients into the cost function given in equation 64 and simplifying, we get

$$C(\delta_{ei}, \delta_{zi}) = \frac{1}{\sqrt{\Lambda^2 (\delta_{zi} - 1)^2 + \text{var}(F - P) (\tau + \tau_e \delta_{ei} (2 - \delta_{ei}) + \tau_p \delta_{zi} (2 - \delta_{zi}))}}.$$

□

## A.4 Proof of Corollary 1

Taking derivatives of the return-volume characteristics in Lemma (2) with respect to  $\delta_e$  gives:

$$\frac{\partial \sigma_R^2}{\partial \delta_e} = -\frac{2\gamma^2 \tau_e (\gamma^6 + \delta_e \tau_e \tau_z (3\gamma^4 + \gamma^2 \tau_z (3\delta_e \tau_e + \tau) + \delta_e^2 \tau_e^2 \tau_z^2))}{\tau_z (\gamma^2 \tau + \delta_e \tau_e (\gamma^2 + \delta_e \tau_e \tau_z))^3} < 0 \quad (65)$$

$$\frac{\partial \theta}{\partial \delta_e} = \frac{\gamma^4 \tau \tau_e \tau_z (\gamma^2 (2\delta_e \tau_e + \tau) + 3\delta_e^2 \tau_e^2 \tau_z)}{(\gamma^2 + \delta_e \tau_e \tau_z)^2 (\gamma^2 \tau + \delta_e^2 \tau_e^2 \tau_z)^2} > 0 \quad (66)$$

$$\frac{\partial \tau_p}{\partial \delta_e} = \frac{2\delta_e \tau_e^2 \tau_z}{\gamma^2} > 0 \quad (67)$$

$$\frac{\partial \mathbb{E}[\mathcal{V}]}{\partial \delta_e} = \frac{\sqrt{\frac{2}{\pi}} \delta_e \tau_e}{\gamma \sqrt{\frac{\gamma^2 + \delta_e^2 \tau_e \tau_z}{\tau_z}}} > 0 \quad (68)$$

which establishes the result.  $\square$

## A.5 Proof of Proposition 3

Equation (54) shows that marginal anticipated utility is weakly increasing in  $\delta_{e,i}$ . As long as  $\frac{\partial C(1, \delta_z)}{\partial \delta_{e,i}} = 0$  (which holds under any well-behaved cost function), then the first-order condition in a symmetric equilibrium

$$\frac{\tau_e}{2 \left( \frac{(1-\Lambda)^2}{\tau} + \frac{\Lambda^2}{\delta_z \tau_p} \right)^{\frac{1}{2}} (\tau_e \delta_e + \delta_z \tau_p + \tau)^{\frac{3}{2}}} = \frac{\partial C(1, \delta_z)}{\partial \delta_{e,i}} \quad (69)$$

implies that  $\delta_e \geq 1$  with  $\delta_e > 1$  if  $\delta_z \neq 0$ . This proves the first half of the proposition.

Lemma 1 implies that in any symmetric equilibrium, we have  $\Lambda = \frac{\delta_e \tau_e + \delta_z \tau_p}{\tau + \delta_e \tau_e + \delta_z \tau_p}$ . Moreover, note that  $\frac{\partial}{\partial \delta_{z,i}} AU = 0$  at

$$\bar{\delta}_{z,i} = \frac{1}{\tau_p} \left( \frac{\Lambda}{1-\Lambda} \right) \sqrt{\tau (\delta_e \tau_e + \tau)} \quad (70)$$

$$= \sqrt{1 + \frac{\tau_e}{\tau}} \left( \delta_z + \frac{\tau_e}{\tau_p} \delta_s \right) > \delta_z \quad (71)$$

But this implies  $\frac{\partial}{\partial \delta_{z,i}} AU (\delta_{z,i} = \delta_z) < 0$  since  $\frac{\partial AU}{\partial \delta_{z,i}} < (>) 0$  for all  $\delta_{z,i} < (>) \bar{\delta}_{z,i}$ . Next, note that if  $\delta_{z,i} = \delta_z \geq 1$ , then  $C'(\delta_{z,i}) > 0$ . Taken together, this proves that at any proposed symmetric equilibrium where  $\delta_z > 1$ , investor  $i$  has an incentive to deviate. Thus, the only possible symmetric equilibrium is one in which each investor chooses  $\delta_{z,i} < 1$ . This proves the second half of the proposition.

□

## A.6 Proof of Propositions 4 and 5

For an investor incurring the experienced utility penalty, choosing  $(\delta_{ei}, \delta_{zi})$  yields anticipated utility and cost given by:

$$AU(\delta_{e,i}, \delta_{z,i}) = -\sqrt{\frac{\frac{1}{\tau + \delta_{e,i}\tau_e + \delta_{z,i}\tau_p}}{(1-\Lambda)^2 \frac{1}{\tau} + \Lambda^2 \frac{1}{\delta_{z,i}\tau_p}}} \quad (72)$$

$$C(\delta_{ei}, \delta_{zi}) = \frac{1}{\sqrt{\Lambda^2 (\delta_{zi} - 1)^2 + \left(\frac{(1-\Lambda)^2}{\tau} + \frac{\Lambda^2}{\tau_p}\right) (\tau + \tau_e \delta_{ei} (2 - \delta_{ei}) + \tau_p \delta_{zi} (2 - \delta_{zi}))}}. \quad (73)$$

Let  $\kappa \equiv \left(\frac{\Lambda}{1-\Lambda}\right)^2 \frac{\tau}{\tau_p}$ . Then,

$$AU(\delta_{e,i}, \delta_{z,i}) = -\sqrt{\frac{\tau}{(1-\Lambda)^2}} \sqrt{\frac{1}{\left(1 + \frac{\kappa}{\delta_{zi}}\right) (\tau + \delta_{e,i}\tau_e + \delta_{z,i}\tau_p)}} \quad (74)$$

$$C(\delta_{ei}, \delta_{zi}) = \sqrt{\frac{\tau}{(1-\Lambda)^2}} \sqrt{\frac{1}{(1-\delta_{zi})^2 \kappa \tau_p + (1+\kappa) (\tau + \tau_e \delta_{ei} (2 - \delta_{ei}) + \tau_p \delta_{zi} (2 - \delta_{zi}))}} \quad (75)$$

Suppose all others are playing  $\bar{\delta}_e, \bar{\delta}_z$ . Then,  $\Lambda = \frac{\tau_e \bar{\delta}_e + \tau_p \bar{\delta}_z}{\tau + \tau_e \bar{\delta}_e + \tau_p \bar{\delta}_z}$  and so

$$\kappa = \left(\frac{\Lambda}{1-\Lambda}\right)^2 \frac{\tau}{\tau_p} = \frac{\gamma^2 (\tau_e \bar{\delta}_e + \tau_p \bar{\delta}_z)^2}{\tau \tau_e^2 \tau_z \bar{\delta}_e^2}. \quad (76)$$

Then,  $(1, 0)$  is a symmetric equilibrium iff

$$AU(1, 0) - C(1, 0) > AU(\delta_{e,i}, \delta_{z,i}) - C(\delta_{e,i}, \delta_{z,i}) \quad (77)$$

for all  $\delta_{e,i}, \delta_{z,i}$ , or equivalently,

$$H \equiv 1 + R - L > 0 \quad (78)$$



where

$$R \equiv \frac{AU(\delta_{e,i}, \delta_{z,i})}{-C(\delta_{ei}, \delta_{zi})} \quad (79)$$

$$= \sqrt{\frac{\gamma^4 \tau \delta_z \tau_z \left( \tau_e \left( \frac{\tau_e \tau_z \bar{\delta}_e^2 (\bar{\delta}_z^2 - (\delta_z - 2)\delta_z)}{\gamma^2} + 2\bar{\delta}_e \bar{\delta}_z - (\delta_e - 2)\delta_e \right) + \frac{\tau_e (\tau_e \tau_z \bar{\delta}_e^2 - \gamma^2 (\delta_e - 2)\delta_e) (\tau_e \tau_z \bar{\delta}_e \bar{\delta}_z + \gamma^2)^2}{\gamma^4 \tau \tau_z} + \tau + \frac{\gamma^2}{\tau_z} \right)}{(\tau_e^2 \delta_z \tau_z \bar{\delta}_e^2 + \gamma^2 (\delta_e \tau_e + \tau)) ((\tau_e \tau_z \bar{\delta}_e \bar{\delta}_z + \gamma^2)^2 + \gamma^2 \tau \delta_z \tau_z)}} \quad (80)$$

$$L \equiv \frac{C(1, 0)}{C(\delta_{ei}, \delta_{zi})} \quad (81)$$

$$= \sqrt{\frac{\tau_e \left( \frac{\tau_e \tau_z \bar{\delta}_e^2 (\bar{\delta}_z^2 - (\delta_z - 2)\delta_z)}{\gamma^2} + 2\bar{\delta}_e \bar{\delta}_z - (\delta_e - 2)\delta_e \right) + \frac{\tau_e (\tau_e \tau_z \bar{\delta}_e^2 - \gamma^2 (\delta_e - 2)\delta_e) (\tau_e \tau_z \bar{\delta}_e \bar{\delta}_z + \gamma^2)^2}{\gamma^4 \tau \tau_z} + \tau + \frac{\gamma^2}{\tau_z}}{(\tau_e + \tau) \left( \frac{(\tau_e \tau_z \bar{\delta}_e \bar{\delta}_z + \gamma^2)^2}{\gamma^2 \tau \tau_z} + 1 \right) + \frac{\tau_e^2 \bar{\delta}_e^2 (\tau_e \tau_z \bar{\delta}_e \bar{\delta}_z + \gamma^2)^2}{\gamma^4 \tau}} \quad (82)$$

Note that

$$\lim_{\gamma \rightarrow \infty} R = \sqrt{\frac{((2 - \delta_e) \delta_e \tau_e + \tau) \delta_z}{\delta_e \tau_e + \tau}}, \quad \lim_{\gamma \rightarrow \infty} L = \sqrt{\frac{(2 - \delta_e) \delta_e \tau_e + \tau}{\tau_e + \tau}} \quad (83)$$

$$\lim_{\gamma \rightarrow \infty} H = 1 + \sqrt{\frac{((2 - \delta_e) \delta_e \tau_e + \tau) \delta_z}{\delta_e \tau_e + \tau}} - \sqrt{\frac{(2 - \delta_e) \delta_e \tau_e + \tau}{\tau_e + \tau}} \quad (84)$$

$$\geq 1 + \sqrt{\frac{((2 - \delta_e) \delta_e \tau_e + \tau) \delta_z}{\delta_e \tau_e + \tau}} - \sqrt{\frac{\tau_e + \tau}{\tau_e + \tau}} \geq 0 \quad (85)$$

which implies (1, 0) is an equilibrium for  $\gamma$  sufficiently high.

Next, note that,

$$\lim_{\gamma \rightarrow 0} R = \lim_{\gamma \rightarrow 0} L = \sqrt{\frac{\frac{\tau_e^4 \tau_z^2 \bar{\delta}_e^4 \bar{\delta}_z^2}{\tau}}{\frac{\tau_e^4 \tau_z^2 \bar{\delta}_e^4 \bar{\delta}_z^2}{\tau}}} = 1, \quad (86)$$

so that

$$\lim_{\gamma \rightarrow 0} H = 1 + R - L > 0 \quad (87)$$

which implies that for sufficiently low  $\gamma$ , an investor prefers to deviate to (1, 0) for any

$\bar{\delta}_e, \bar{\delta}_z \neq 0$ . Finally, consider an equilibrium in which  $\bar{\delta}_e = 1, \bar{\delta}_z = 0$ . In this case,

$$\lim_{\gamma \rightarrow 0} R = \lim_{\gamma \rightarrow 0} \sqrt{2 - \delta_z} \quad (88)$$

$$\lim_{\gamma \rightarrow 0} L = \lim_{\gamma \rightarrow 0} \frac{1}{\gamma} \sqrt{(2 - \delta_z)} = \infty \quad (89)$$

which suggests that

$$\lim_{\gamma \rightarrow 0} H < 0 \quad (90)$$

and so  $(1, 0)$  cannot be an equilibrium for  $\gamma$  sufficiently low. However,

$$\lim_{\gamma \rightarrow \infty} R = \sqrt{\frac{((2 - \delta_e) \delta_e \tau_e + \tau) \delta_z}{\delta_e \tau_e + \tau}}, \quad \lim_{\gamma \rightarrow \infty} L = \sqrt{\frac{(2 - \delta_e) \delta_e \tau_e + \tau}{\tau_e + \tau}} \quad (91)$$

which implies  $\lim_{\gamma \rightarrow \infty} H \geq 0$  as before, and so  $(1, 0)$  is an equilibrium for  $\gamma$  sufficiently high.  $\square$

## A.7 Proof of Corollary 2

Denote the return characteristics in the rational expectations equilibrium (symmetric equilibrium) by  $RE$  ( $SE$ , respectively). Note that

$$\theta_{RE} - \theta_{OE} = -\frac{\tau \tau_e^2 \tau_z^2}{(\gamma^2 + \tau_e \tau_z)(\gamma^2 \tau + \tau_e^2 \tau_z)} < 0 \quad (92)$$

$$\tau_{p,RE} - \tau_{p,OE} = 0 \quad (93)$$

$$\mathbb{E}[\mathcal{V}_{RE}] - \mathbb{E}[\mathcal{V}_{OE}] = \frac{\sqrt{\frac{2}{\pi}} \left( \sqrt{\frac{\gamma^2 + \tau_e \tau_z}{\tau_z(\gamma^2(\tau_e + \tau) + \tau_e^2 \tau_z)^2}} (\gamma^2(\tau_e + \tau) + \tau_e^2 \tau_z) - \gamma^2(\tau_e + \tau) \sqrt{\frac{\gamma^2 + \tau_e \tau_z}{\gamma^4(\tau_e + \tau)^2 \tau_z}} \right)}{\gamma} = 0 \quad (94)$$

Finally, note that

$$\sigma_{R,RE}^2 - \sigma_{R,OE}^2 = \frac{\tau (\tau_p^2 + \tau \tau_p - 2\tau_e(\tau_e + \tau))}{(\tau_e + \tau)^2 (\tau_e + \tau_p + \tau)^2}, \quad (95)$$

which is positive iff  $\tau_p > \frac{1}{2} \sqrt{8\tau\tau_e + 8\tau_e^2 + \tau^2} - \frac{\tau}{2}$ .  $\square$

## A.8 Proof of Lemma 4

Suppose  $\lambda$  fraction of investors chose  $(\delta_{z1}, \delta_{e1})$  and  $(1 - \lambda)$  investors chose  $(\delta_{z2}, \delta_{e2})$ . This implies that price is given by

$$P = m + \Lambda (s_p - m) \text{ , where } \Lambda = \frac{(\lambda \delta_{e1} + (1 - \lambda) \delta_{e2}) \tau_e + (\lambda \delta_{z1} + (1 - \lambda) \delta_{z2}) \tau_p}{\tau + (\lambda \delta_{e1} + (1 - \lambda) \delta_{e2}) \tau_e + (\lambda \delta_{z1} + (1 - \lambda) \delta_{z2}) \tau_p}.$$

Assume that risk aversion is not sufficiently high, this implies that investor's objective function has a local interior maxima. Investor then evaluates his objective at this interior maxima and the boundary  $\delta_{zi} = 0$  and chooses the one where his objective is highest. For the mixed equilibrium to sustain, we need  $\delta_{z1} = 0$  (which implies  $\delta_{e1} = 1$ ) and  $\delta_{z2} = \delta_z^* \geq 1$  (and let  $\delta_{e2} = \delta_e^*$ ). For this mixed equilibrium, investor has to be indifferent between the two points, which implies that the following conditions have to hold:

$$\begin{aligned} \frac{\partial AU}{\partial \delta_{ei}} \Big|_{\{\delta_{zi}=\delta_z^*, \delta_{ei}=\delta_e^*\}} &= C'(\delta_e^*) \\ \frac{\partial AU}{\partial \delta_{zi}} \Big|_{\{\delta_{zi}=\delta_z^*, \delta_{ei}=\delta_e^*\}} &= C'(\delta_z^*) \\ AU(0, 1) - C(0, 1) &= AU(\delta_z^*, \delta_e^*) - C(\delta_z^*, \delta_e^*). \end{aligned} \quad (96)$$

The first two conditions are the FOCs for local maxima  $(\delta_z^*, \delta_e^*)$  and the third condition says that investors are indifferent between the local maxima and the corner solution  $(0, 1)$ . These three equations will help us solve for 3 unknowns  $\delta_z^*$ ,  $\delta_e^*$  and  $\lambda$ . Suppose  $\bar{\delta}_e = \bar{\delta}_e = (\lambda + (1 - \lambda) \delta_e)$  and  $\bar{\delta}_z = (1 - \lambda) \delta_z$  denote the average action of investors. The FOCs can be rewritten as

$$R^3 = \frac{2(\delta_z^* - 1)}{1 - (\delta_e^* \tau_e + \tau) \frac{(\bar{\delta}_e \tau_e + \bar{\delta}_z \tau_p)^2}{\tau_p^2 \delta_z^{*2} \tau}} \quad (97)$$

$$R^3 = \frac{2(\delta_e^* - 1)}{1 + \frac{\Lambda^2}{\tau_p \text{var}(F-P)} \left( \frac{1}{\delta_z^*} - 1 \right)}, \quad (98)$$

where

$$R^2 = \frac{\frac{(\bar{\delta}_e \tau_e + \bar{\delta}_z \tau_p)^2}{\tau^2} + \left( \frac{1}{\tau} + \frac{(\bar{\delta}_e \tau_e + \bar{\delta}_z \tau_p)}{\tau^2 \tau_p} \right) (\tau + \tau_e \delta_e^* (2 - \delta_e^*)) + \frac{\tau_p}{\tau} \delta_z^* (2 - \delta_z^*)}{\left( \frac{1}{\tau} + \frac{(\bar{\delta}_e \tau_e + \bar{\delta}_z \tau_p)}{\delta_z^* \tau_p \tau^2} \right) (\tau + \delta_e^* \tau_e + \delta_z^* \tau_p)}.$$

Since any deviations from rational expectations generate higher anticipated utility and lower true utility,  $R < 1$ . Using this inequality in equation 97 gives us that  $\delta_z^* < \frac{3}{2}$ . Similarly, using

$R < 1$  in equation 98 gives us that  $1 < \delta_e^* < \frac{3}{2}$ .

Moreover  $\Lambda_{RE} > \lambda_{AE} \iff \tau_e + \frac{\tau_p}{\delta_e^2} > \bar{\delta}_e \tau_e + \bar{\delta}_z \tau_p$ . Let  $x$  denote the ratio of these two i.e.,

$$x = \frac{\bar{\delta}_e \tau_e + \bar{\delta}_z \tau_p}{\tau_e + \frac{\tau_p}{\delta_e^2}}.$$

We need to prove that  $x < 1$ . Take the limit as  $\gamma \rightarrow 0$ ,

$$\begin{aligned} \lim_{\gamma \rightarrow 0} R^2 &= \lim_{\tau_p \rightarrow \infty} \frac{\frac{\left(\tau_e + \frac{\tau_p}{\delta_e^2}\right)^2 x^2}{\tau^2} + \left(\frac{1}{\tau} + \frac{\left(\tau_e + \frac{\tau_p}{\delta_e^2}\right)^2 x^2}{\tau^2 \tau_p}\right) (\tau + \tau_e \delta_e^* (2 - \delta_e^*)) + \frac{\tau_p}{\tau} \delta_z^* (2 - \delta_z^*)}{\left(\frac{1}{\tau} + \frac{\left(\tau_e + \frac{\tau_p}{\delta_e^2}\right)^2 x^2}{\delta_z^* \tau_p \tau^2}\right) (\tau + \delta_e^* \tau_e + \delta_z^* \tau_p)} \\ &= \lim_{\tau_p \rightarrow \infty} \frac{\frac{\left(\frac{\tau_p}{\delta_e^2}\right)^2 x^2}{\tau^2} + \frac{\left(\frac{\tau_p}{\delta_e^2}\right)^2 x^2}{\tau^2 \tau_p} (\tau + \tau_e \delta_e^* (2 - \delta_e^*)) + \frac{\tau_p}{\tau} \delta_z^* (2 - \delta_z^*)}{\left(\frac{\delta_z^* \tau_p}{\tau} + \frac{\left(\frac{\tau_p}{\delta_e^2}\right)^2 x^2}{\tau^2}\right)} \end{aligned}$$

There are 2 cases to consider, Case 1:  $\tau_p x \rightarrow \infty$ , Case 2:  $\tau_p x \rightarrow \text{constant}$ . In case 2, it is immediate that  $x < 1$  for sufficiently large  $\tau_p$  i.e., for sufficiently large  $\gamma$ . Next, I will prove that case 1 is not possible in our setting.

Suppose, for now, case 1 is possible. In this case,  $\tau_p x \rightarrow \infty$  as  $\gamma \rightarrow 0$ . In this case,

$$\begin{aligned} \lim_{\gamma \rightarrow 0} R^2 &= \lim_{\tau_p \rightarrow \infty} \frac{\frac{\left(\frac{\tau_p}{\delta_e^2}\right)^2 x^2}{\tau^2} + \frac{\left(\frac{\tau_p}{\delta_e^2}\right)^2 x^2}{\tau^2 \tau_p} (\tau + \tau_e \delta_e^* (2 - \delta_e^*)) + \frac{\tau_p}{\tau} \delta_z^* (2 - \delta_z^*)}{\left(\frac{\delta_z^* \tau_p}{\tau} + \frac{\left(\frac{\tau_p}{\delta_e^2}\right)^2 x^2}{\tau^2}\right)} \\ &= 1 \end{aligned}$$

and the indifference condition of the investor becomes

$$\lim_{\tau_p \rightarrow \infty} \frac{\sqrt{\frac{\left(\frac{\tau_p}{\delta_e^2}\right)^2 x^2}{\tau^2} + \left(\frac{1}{\tau} + \frac{\left(\frac{\tau_p}{\delta_e^2}\right)^2 x^2}{\tau^2 \tau_p}\right) (\tau + \tau_e \delta_e^* (2 - \delta_e^*)) + \frac{\tau_p}{\tau} \delta_z^* (2 - \delta_z^*)}}{\sqrt{\frac{\left(\frac{\tau_p}{\delta_e^2}\right)^2 x^2}{\tau^2}}} = 2$$

The LHS of above expression is 1 and hence indifference condition cannot be satisfied. This

implies that case 1 is not possible. This implies that  $\tau_p x$  tends to a finite constant. This immediately implies that for  $\gamma$  sufficiently low,  $x < 1$ .

□

## A.9 Proof of Corollary 3

Denote the return characteristics in the rational expectations equilibrium (subjective beliefs asymmetric equilibrium) by  $RE$  ( $AE$ , respectively). Let  $\bar{\delta}_e = \lambda + (1 - \lambda) \delta_e^*$  and  $\bar{\delta}_z = (1 - \lambda) \delta_z^*$  denote the average beliefs about the precision of private signals and price signal. Note that

$$\tau_{p,AE} - \tau_{p,RE} = \frac{\tau_z \tau_e^2}{\gamma^2} (\bar{\delta}_e^2 - 1) > 0.$$

$$\begin{aligned} \theta_{AE} - \theta_{RE} &= \frac{\tau_z}{\Lambda_{AE} (\beta_{AE}^2 \tau + \tau_z)} - \frac{\tau_z}{\Lambda_{RE} (\beta_{RE}^2 \tau + \tau_z)} \\ &= \frac{\tau_z}{\Lambda_{AE} \left( \frac{\beta^2}{\bar{\delta}_e^2} \tau + \tau_z \right)} \left( 1 - \frac{\Lambda_{AE}}{\Lambda_{RE}} \frac{\beta^2 \tau + \bar{\delta}_e^2 \tau_z}{\bar{\delta}_e^2 \beta^2 \tau + \bar{\delta}_e^2 \tau_z} \right) \end{aligned}$$

Since  $\bar{\delta}_e > 1$ , we have  $\frac{\beta^2 \tau + \bar{\delta}_e^2 \tau_z}{\bar{\delta}_e^2 \beta^2 \tau + \bar{\delta}_e^2 \tau_z} < 1$ . Moreover, since  $\frac{\Lambda_{AE}}{\Lambda_{RE}} < 1$  by Lemma 4, we have  $\theta_{AE} > \theta_{RE}$ .

$$\mathbb{E}[\mathcal{V}] = \int_i \frac{\omega_i}{\gamma} \sqrt{\frac{2}{\pi} \left( \frac{(A_i + B_i - \Lambda)^2}{\tau} + \frac{A_i^2}{\tau_e} + \frac{(B_i - \Lambda)^2}{\tau_p} \right)} di \quad (99)$$

$$\mathbb{E}[\mathcal{V}_{AE}] = \lambda V_1 + (1 - \lambda) V_2, \text{ where} \quad (100)$$

$$V_1 \equiv \frac{(\tau_e + \tau)}{\gamma} \sqrt{\frac{2}{\pi} \left( \frac{1}{\tau} \left( \frac{\tau_e}{\tau + \tau_e} - \Lambda_{AE} \right)^2 + \frac{1}{\tau_e} \left( \frac{\tau_e}{\tau + \tau_e} \right)^2 + \frac{1}{\tau_{p,AE}} \Lambda_{AE}^2 \right)} \quad (101)$$

$$V_2 \equiv \frac{\tau + \delta_e^* \tau_e + \delta_z^* \tau_{p,AE}}{\gamma} \sqrt{\frac{2}{\pi} \left( \frac{1}{\tau} \left( \frac{\delta_e^* \tau_e + \delta_z^* \tau_{p,AE}}{\tau + \delta_e^* \tau_e + \delta_z^* \tau_{p,AE}} - \Lambda_{AE} \right)^2 + \frac{1}{\tau_e} \left( \frac{\delta_e^* \tau_e}{\tau + \delta_e^* \tau_e + \delta_z^* \tau_{p,AE}} \right)^2 + \frac{1}{\tau_{p,AE}} \left( \frac{\delta_z^* \tau_{p,AE}}{\tau + \delta_e^* \tau_e + \delta_z^* \tau_{p,AE}} - \Lambda_{AE} \right)^2 \right)} \quad (102)$$

Let

$$A(x) = \frac{x\tau_e + (1-x)\delta_e^*\tau_e}{x(\tau + \tau_e) + (1-x)(\tau + \delta_e^*\tau_e + \delta_z^*\tau_{p,AE})} \quad (103)$$

$$B(x) = \frac{x0 + (1-x)(\delta_z^*\tau_p)}{x(\tau + \tau_e) + (1-x)(\tau + \delta_e^*\tau_e + \delta_z^*\tau_{p,AE})} \quad (104)$$

$$\omega(x) = x(\tau_e + \tau) + (1-x)(\tau + \delta_e^*\tau_e + \delta_z^*\tau_{p,AE}) \quad (105)$$

$$V(x) = \frac{\omega(x)}{\gamma} \sqrt{\frac{2}{\pi} \left( \frac{1}{\tau} (A(x) + B(x) - \Lambda)^2 + \frac{1}{\tau_e} A(x)^2 + \frac{1}{\tau_p} (B(x) - \Lambda)^2 \right)} \quad (106)$$

and

$$\mathbb{E}[\mathcal{V}_{AE}] = \lambda V(1) + (1-\lambda)V(0) \quad (107)$$

Note that

$$V(\lambda) = \frac{\omega(\lambda)}{\gamma} \sqrt{\frac{2}{\pi} \left( \frac{1}{\tau_e} A(\lambda)^2 + \frac{1}{\tau_{p,RE}} (B(\lambda) - \Lambda)^2 \right)} \quad (108)$$

$$= \frac{1}{\gamma} \sqrt{\frac{2}{\pi} \left( \frac{(\lambda\tau_e + (1-\lambda)\delta_e^*\tau_e)^2}{\tau_e} + \frac{((1-\lambda)(\delta_z^*\tau_p) - \lambda(\tau_e + 0\tau_p) - (1-\lambda)(\delta_e^*\tau_e + \delta_z^*\tau_p))^2}{\tau_{p,RE}} \right)} \quad (109)$$

$$= \frac{1}{\gamma} \sqrt{\frac{2}{\pi} \left( \frac{(\lambda\tau_e + (1-\lambda)\delta_e^*\tau_e)^2}{\tau_e} + \frac{(\lambda\tau_e + (1-\lambda)\delta_e^*\tau_e)^2}{\tau_{p,RE}} \right)} \quad (110)$$

$$= \frac{1}{\gamma} \sqrt{\frac{2}{\pi} \left( \delta_e^2\tau_e + \frac{\tau_e^2}{\tau_p} \right)} \geq \frac{1}{\gamma} \sqrt{\frac{2}{\pi} \left( \tau_e + \frac{\tau_e^2}{\tau_p} \right)} = \mathbb{E}[\mathcal{V}_{RE}] \quad (111)$$

where  $\delta_e \equiv \lambda + (1-\lambda)\delta_e^*$ . It remains to be shown that:

$$\lambda V(1) + (1-\lambda)V(0) \geq V(\lambda) \quad (112)$$

Note that

$$V(x) = \frac{1}{\gamma} \sqrt{\frac{2}{\pi} \left( \frac{1}{\tau} (\alpha(x) + \beta(x) - \Lambda\omega(x))^2 + \frac{1}{\tau_e} \alpha(x)^2 + \frac{1}{\tau_p} (\beta(x) - \Lambda\omega(x))^2 \right)} \quad (113)$$

where

$$\alpha(x) = x\tau_e + (1-x)\delta_e^*\tau_e \equiv a_0 + a_1x \quad (114)$$

$$\beta(x) = x0 + (1-x)(\delta_z^*\tau_p) \equiv b_0 + b_1x \quad (115)$$

$$\omega(x) = x(\tau_e + \tau) + (1-x)(\tau + \delta_e^*\tau_e + \delta_z^*\tau_{p,AE}) \equiv w_0 + w_1x \quad (116)$$

$$\frac{V_{xx}}{V^3} = 4 \frac{\tau + \tau_e + \tau_p}{\pi^2 \gamma^4 \tau \tau_e \tau_p} (-a_0b_1 + a_0\Lambda w_1 + a_1b_0 - a_1\Lambda w_0)^2 > 0 \quad (117)$$

which implies  $V(x)$  is convex, which implies:

$$\mathbb{E}[\mathcal{V}_{AE}] = \lambda V(1) + (1 - \lambda)V(0) \geq V(\lambda) \geq \mathbb{E}[\mathcal{V}_{RE}] \quad (118)$$

## A.10 Proof of Proposition 6

The utility of noise traders is

$$\begin{aligned} U_z &= -E(\gamma_z \exp\{+\gamma_z z(F - P)\}) \\ &= -E(\gamma_z \exp\{\gamma_z z F(1 - \Lambda) - \gamma_z \Lambda \beta z^2\}) \\ &= -E\left(\gamma_z \exp\left\{\left(\frac{\gamma_z^2(1 - \Lambda)^2}{2\tau} - \gamma_z \Lambda \beta\right) z^2\right\}\right) \\ &= -\gamma_z \frac{1}{\sqrt{1 - 2\frac{1}{\tau_z}\left(\left(\frac{\gamma_z^2(1 - \Lambda)^2}{2\tau} - \gamma_z \Lambda \beta\right)\right)}} \\ &= -\gamma_z \sqrt{\frac{\tau_z}{\tau_z - \frac{\gamma_z^2(1 - \Lambda)^2}{\tau} + 2\gamma_z \Lambda \beta}} \end{aligned}$$

where we used the fact that  $E(e^{ae^2}) = \frac{1}{\sqrt{1 - 2a\sigma_\epsilon^2}}$ . This implies that utility of noise traders is monotonically decreasing in  $\frac{\gamma_z(1 - \Lambda)^2}{2\tau} - \Lambda\beta$ .

(i) Rational expectations vs. Symmetric equilibrium: In this case,  $\bar{\delta}_e = 1$  and

$$\Lambda_{SE} = \frac{\tau_e}{\tau + \tau_e}, \quad \Lambda_{RE} = \frac{\tau_e + \tau_p}{\tau + \tau_e + \tau_p} \quad (119)$$

so

$$U_{SE} - U_{RE} > 0 \quad (120)$$

$$\Leftrightarrow \frac{\gamma\tau\tau_p}{\tau_e(\tau_e + \tau)(\tau_e + \tau_p + \tau)} > \frac{\tau\gamma_z}{2} \frac{\tau_p(2\tau_e + \tau_p + 2\tau)}{(\tau_e + \tau)^2(\tau_e + \tau_p + \tau)^2} \quad (121)$$

$$\Leftrightarrow \frac{\gamma}{\gamma_z} > \frac{\tau_e}{\tau + \tau_e} \frac{2(\tau_e + \tau) + \tau_p}{2(\tau_e + \tau_p + \tau)} \quad (122)$$

which implies if  $\gamma \geq \gamma_z$ , then  $U_{SE} > U_{RE}$ .

(ii) Rational Expectations vs. Asymmetric Equilibrium: In this case,  $\bar{\delta}_e \geq 1$  and

$$\Lambda_{RE} = \frac{\tau_e + \tau_p}{\tau + \tau_e + \tau_p}, \quad \Lambda_{AE} = \frac{\delta_e \tau_e + \delta_z \tau_p}{\tau + \delta_e \tau_e + \delta_z \tau_p} \quad (123)$$

so that

$$U_{AE} - U_{RE} > 0 \quad (124)$$

$$\Leftrightarrow \gamma \left( \frac{\Lambda_{RE}}{\tau_e} - \frac{\Lambda_{AE}}{\tau_e \delta_e} \right) > \gamma_z \left( \frac{(1-\Lambda_{AE})^2}{2\tau} - \frac{(1-\Lambda_{RE})^2}{2\tau} \right) \quad (125)$$

$$\Leftrightarrow \frac{\gamma}{\tau_e} \left( \Lambda_{RE} - \frac{\Lambda_{AE}}{\delta_e} \right) > \frac{\gamma_z}{2\tau} (\Lambda_{RE} - \Lambda_{AE}) (2 - (\Lambda_{AE} + \Lambda_{RE})) \quad (126)$$

Note that  $\delta_e \geq 1$ , so it is sufficient to establish:

$$\frac{\gamma}{\tau_e} (\Lambda_{RE} - \Lambda_{AE}) > \frac{\gamma_z}{2\tau} (\Lambda_{RE} - \Lambda_{AE}) (2 - (\Lambda_{AE} + \Lambda_{RE})) \quad (127)$$

When  $\Lambda_{RE} > \Lambda_{AE}$ , the above is equivalent to:

$$\frac{\gamma}{\gamma_z} > \frac{\tau_e}{2} \left( \frac{1}{\tau + \tau_e + \tau_p} + \frac{1}{\tau + \delta_e \tau_e + \delta_z \tau_p} \right) \quad (128)$$

which is always true if  $\gamma \geq \gamma_z$ .

(iii) Total welfare is given by:

$$W(\delta_e, \delta_z) = -\frac{1}{\sqrt{\Lambda^2(\delta_z-1)^2 + \left(\frac{(1-\Lambda)^2}{\tau} + \frac{\Lambda^2}{\tau_p}\right)(\tau + \tau_e \delta_e(2-\delta_e) + \tau_p \delta_z(2-\delta_z))}} - \sqrt{\frac{\tau_z}{\tau_z - \frac{\gamma_z^2(1-\Lambda)^2}{\tau} + 2\gamma_z \Lambda \beta}} \quad (129)$$

Moreover, for the rational expectations equilibrium, we have  $\delta_e = \delta_z = 1$ , so that

$$W_{RE} = -\frac{1}{\sqrt{\left(\frac{(1-\Lambda_{RE})^2}{\tau} + \frac{\Lambda^2}{\tau_p}\right)(\tau + \tau_e + \tau_p)}} - \sqrt{\frac{\tau_z}{\tau_z - \frac{\gamma_z^2(1-\Lambda_{RE})^2}{\tau} + 2\gamma_z \Lambda_{RE} \beta_{RE}}} \quad (130)$$

This implies that the difference in welfare is:

$$W_{OE} - W_{RE} = \frac{1}{\sqrt{\left(\frac{(1-\Lambda_{RE})^2}{\tau} + \frac{\Lambda^2}{\tau_p}\right)(\tau + \tau_e + \tau_p)}} + \sqrt{\frac{\tau_z}{\tau_z - \frac{\gamma_z^2(1-\Lambda_{RE})^2}{\tau} + 2\gamma_z \Lambda_{RE} \beta_{RE}}} - \frac{1}{\sqrt{\Lambda_{OE}^2(\delta_z-1)^2 + \left(\frac{(1-\Lambda_{OE})^2}{\tau} + \frac{\Lambda_{OE}^2}{\tau_p}\right)(\tau + \tau_e \delta_e(2-\delta_e) + \tau_p \delta_z(2-\delta_z))}} - \sqrt{\frac{\tau_z}{\tau_z - \frac{\gamma_z^2(1-\Lambda_{OE})^2}{\tau} + 2\gamma_z \Lambda_{OE} \beta_{OE}}} \quad (131)$$



Above, we have established that when  $\gamma_z \leq \gamma$  and  $\Lambda_{OE} < \Lambda_{RE}$ , we have:

$$U_{z,OE} = -\sqrt{\frac{\tau_z}{\tau_z - \frac{\gamma^2(1-\Lambda_{OE})^2}{\tau} + 2\gamma\Lambda_{OE}\beta_{OE}}} > -\sqrt{\frac{\tau_z}{\tau_z - \frac{\gamma_z^2(1-\Lambda_{RE})^2}{\tau} + 2\gamma_z\Lambda_{RE}\beta_{RE}}} = U_{z,RE} \quad (132)$$

$$\Leftrightarrow \tau_z - \frac{\gamma_z^2(1-\Lambda_{OE})^2}{\tau} + 2\gamma_z\Lambda_{OE}\beta_{OE} \geq \tau_z - \frac{\gamma_z^2(1-\Lambda_{RE})^2}{\tau} + 2\gamma_z\Lambda_{RE}\beta_{RE} > 0 \quad (133)$$

Let

$$\bar{\gamma} \equiv \frac{\tau_z - \frac{\gamma_z^2(1-\Lambda_{RE})^2}{\tau}}{\frac{2\gamma_z\Lambda_{RE}}{\tau_e}} = \frac{\tau_e(\tau_z(\tau_e+\tau_p+\tau)^2 - \tau\gamma_z^2)}{2\gamma_z(\tau_e+\tau_p)(\tau_e+\tau_p+\tau)}. \quad (134)$$

Note that

$$\lim_{\gamma \uparrow \bar{\gamma}} \sqrt{\frac{\tau_z}{\tau_z - \frac{\gamma_z^2(1-\Lambda_{RE})^2}{\tau} + 2\gamma_z\Lambda_{RE}\beta_{RE}}} = \infty, \quad (135)$$

but

$$\lim_{\gamma \uparrow \bar{\gamma}} \frac{\frac{1}{\sqrt{\left(\frac{(1-\Lambda_{RE})^2}{\tau} + \frac{\Lambda_p^2}{\tau_p}\right)(\tau+\tau_e+\tau_p)}} - \sqrt{\frac{\tau_z}{\tau_z - \frac{\gamma_z^2(1-\Lambda_{OE})^2}{\tau} + 2\gamma_z\Lambda_{OE}\beta_{OE}}}}{\frac{1}{\sqrt{\Lambda_{OE}^2(\delta_z-1)^2 + \left(\frac{(1-\Lambda_{OE})^2}{\tau} + \frac{\Lambda_{OE}^2}{\tau_p}\right)(\tau+\tau_e\delta_e(2-\delta_e)+\tau_p\delta_z(2-\delta_z))}}} \geq -c \quad (136)$$

for some  $c \leq \infty$ . This implies

$$\lim_{\gamma \rightarrow \bar{\gamma}} W_{OE} - W_{RE} > 0, \quad (137)$$

or equivalently,  $\exists \underline{\gamma} \leq \bar{\gamma}$ , such that for all  $\gamma > \underline{\gamma}$ ,  $W_{OE} > W_{RE}$ .  $\square$

## B Extensions

### B.1 Beliefs about others

In this section, we provide a micro-foundation for the alternative interpretations of the subjective belief parameter  $\delta_{z,i}$ . As before, we assume that investor  $i$  observes signals

$$s_i = F + \varepsilon_i \quad (138)$$

where

$$F \sim N\left(0, \frac{1}{\tau}\right), \quad \varepsilon_i \sim N\left(0, \frac{1}{\tau_e}\right). \quad (139)$$

In addition, there exists a continuum of liquidity traders with individual demand  $e_i = \psi z + \sqrt{1-\psi^2}\nu_i$ , so that the aggregate noisy supply is  $\psi z \sim N\left(0, \frac{\psi^2}{\tau_z}\right)$ .

We allow each agent to form subjective beliefs along several dimensions. Specifically, investor  $i$  chooses  $\delta_{e,i}, \rho_i, \pi_i$  and  $\psi_i$  which transform her beliefs as follows:

$$\varepsilon_i \sim_i N\left(0, \frac{1}{\delta_{e,i}\tau_e}\right) \quad (140)$$

$$\varepsilon_j = \rho_i \eta + \sqrt{1 - \rho_i^2} u_i, \quad \eta, u_i \sim N\left(0, \frac{1}{\pi_i \tau_e}\right) \quad (141)$$

$$e_i \sim_i \psi_i z + \sqrt{1 - \psi_i^2} \nu_i \quad \text{so that total noisy supply is } \psi_i z \sim N\left(0, \frac{\psi_i^2}{\tau_z}\right) \quad (142)$$

Note that  $\rho_i, \psi_i \in [0, 1]$  and  $\delta_{e,i}, \pi_i \in [0, \infty]$ . Intuitively, equation 141 captures the idea that distort their beliefs about both the amount of noise in others' signals ( $\pi_i$ ) but also the average correlation across other investors ( $\rho_i$ ).

Conjecture that, for investor  $i$ , observing the price is equivalent to observing  $s_p = \bar{s} + \beta_i z = F + \rho_i \eta + \beta \psi_i z$ . Then, conditional on  $s_i$  and  $s_p$ , we have:

$$\mathbb{E}[F|s_i, s_p] = m + A_i(s_i - m) + B_i(s_p - m) \equiv \mu_i \quad (143)$$

$$\omega_i \equiv \frac{1}{\text{var}_i[F|s_i, s_p]} = \frac{\tau}{1 - A_i - B_i} = \tau + \delta_i \tau_e + \tau_{p,i} \quad (144)$$

where

$$A_i = \frac{\tau_e \delta_i}{\tau_e \delta_i + \tau + \tau_{p,i}}, \quad B_i = \frac{\tau_{p,i}}{\tau_e \delta_i + \tau + \tau_{p,i}} \quad (145)$$

$$\frac{1}{\tau_{p,i}} = \frac{\rho_i^2}{\pi_i \tau_e} + \frac{\beta^2 \psi_i^2}{\tau_z}.$$

An investor's optimal demand is given by

$$x_i = \frac{\mu_i - P}{\gamma \left(\frac{1}{\omega_i}\right)} \quad (146)$$

and so market clearing implies that in a symmetric equilibrium, we have:

$$P = \bar{\mu} - \gamma \left(\frac{1}{\bar{\omega}}\right) \psi_i z \quad (147)$$

$$= m + (\bar{A} + \bar{B})(s_p - m) \quad (148)$$

$$= m + \Lambda(s_p - m) \quad (149)$$

so that  $\beta = -\frac{\gamma(\frac{1}{\bar{\omega}})}{A}$ . Finally, anticipatory utility is given by

$$\hat{J}_i = -\sqrt{\frac{\text{var}_i(F)}{\text{var}_i(F-P)}} = -\sqrt{\frac{\frac{1}{\omega_i}}{\text{var}_i(F-\Lambda\bar{s}_p)}} = -\sqrt{\frac{\frac{1}{\tau+\delta_i\tau_e+\tau_{p,i}}}{\frac{(1-\Lambda)^2}{\tau_0} + \frac{\Lambda^2}{\tau_{pi}}}}$$

This implies that choices  $\rho_i$ ,  $\pi_i$  and  $\psi_i$  only affect anticipatory utility through  $\tau_{p,i}$ , where

$$\frac{1}{\tau_{p,i}} = \frac{\rho_i^2}{\pi_i\tau_e} + \frac{\beta^2\psi_i^2}{\tau_z}.$$

Note that if investor  $i$  held rational expectations,

$$\frac{1}{\tau_p} = \frac{\beta^2\psi^2}{\tau_z}.$$

We want to define  $\delta_{zi}$  such that  $\tau_{pi} = \delta_{zi}\tau_p$ , which implies that

$$\delta_{zi} = \frac{\frac{\beta^2\psi^2}{\tau_z}}{\frac{\rho_i^2}{\pi_i\tau_e} + \frac{\beta^2\psi_i^2}{\tau_z}}$$

which together with  $\rho_i, \psi_i \in [0, 1]$  and  $\pi_i \in [0, \infty]$  implies that

$$\delta_{zi} \in [0, \infty].$$

## B.2 Belief choice about public signals

In this section, we introduce a public signal  $s_q = F + \eta$ , where  $\eta \sim N(0, \tau_\eta^{-1})$  and is independent of all other random variables. We allow each investor to choose how to interpret the quality of the information in the public signal. Specifically, we assume that investor  $i$  believes that the noise in the public signal is given by

$$\eta \sim_i \mathcal{N}\left(0, \frac{1}{\delta_{\eta,i}\tau_\eta}\right). \quad (150)$$

Given investor  $i$ 's subjective beliefs  $\delta_{e,i}$ ,  $\delta_{z,i}$ , and  $\delta_{\eta,i}$  and conditional on her observed signals,  $s_i, s_p$  and  $s_q$ , investor  $i$ 's posterior subjective beliefs are given by:

$$F|s_i, s_p \sim_i \mathcal{N}\left(\mu_i, \frac{1}{\omega_i}\right), \text{ where} \quad (151)$$

$$\mu_i \equiv \mathbb{E}_i[F|s_i, s_p] = m + A_i(s_i - m) + B_i(s_p - m) + C_i(s_q - m), \quad (152)$$

$$\omega_i \equiv \frac{1}{\text{var}_i[F|s_i, s_p]} = \frac{\tau}{1 - A_i - B_i - C_i}, \text{ and} \quad (153)$$

$$A_i \equiv \frac{\delta_{e,i}\tau_e}{\tau + \delta_{e,i}\tau_e + \delta_{z,i}\tau_p + \delta_{\eta,i}\tau_\eta}, B_i \equiv \frac{\delta_{z,i}\tau_p}{\tau + \delta_{e,i}\tau_e + \delta_{z,i}\tau_p + \delta_{\eta,i}\tau_\eta} \quad C_i \equiv \frac{\delta_{\eta,i}\tau_\eta}{\tau + \delta_{e,i}\tau_e + \delta_{z,i}\tau_p + \delta_{\eta,i}\tau_\eta} \quad (154)$$

Similar to the benchmark model, the price can be written

$$P = m + \Lambda(s_p - m) + C(s_q - m),$$

$$\text{where } \Lambda = \frac{\int_i \delta_{e,i}\tau_e + \delta_{z,i}\tau_p di}{\int_i \tau + \delta_{e,i}\tau_e + \delta_{z,i}\tau_p + \delta_{\eta,i}\tau_\eta di}, \quad C = \frac{\int_i \delta_{\eta,i}\tau_\eta di}{\int_i \tau + \delta_{e,i}\tau_e + \delta_{z,i}\tau_p + \delta_{\eta,i}\tau_\eta di},$$

and where  $s_p = F + \beta z$ ,  $\tau_p = \tau_z/\beta^2$ , and  $\beta = -\frac{\gamma}{\tau_e \int_i \delta_{e,i} di}$ . Given this equilibrium price and investor  $i$ 's subjective beliefs ( $\delta_{e,i}$ ,  $\delta_{z,i}$ , and  $\delta_{\eta,i}$ ), her anticipated utility is

$$AU(\delta_{e,i}, \delta_{z,i}, \delta_{\eta,i}) = -\sqrt{\frac{\text{var}_i[F|s_i, P, s_q]}{\text{var}_i[F - P]}}. \quad (155)$$

This expression closely matches the expression in the benchmark model, found in (39). The numerator captures the information channel, updated to reflect the investor's beliefs about the quality of the public signal. The denominator captures the speculative channel. Using this, we can update Lemma 3 to reflect the inclusion of the public signal.

**Lemma 6.** *Anticipated utility is always*

(i) *(weakly) increasing in  $\delta_{e,i}$ : it is strictly increasing as long as  $\delta_{z,i} > 0$ , and*

(ii) *non-monotonic in  $\delta_{z,i}$ : there exists some  $\bar{\delta}_z$  such that for all  $\delta_{z,i} < \bar{\delta}_z$  anticipated utility is decreasing in  $\delta_{z,i}$  while for all  $\delta_{z,i} > \bar{\delta}_z$  it is increasing.*

*When all other investors ignore public information (i.e.,  $\delta_{\eta,-i} = 0$ ), then investor  $i$ 's anticipated utility is strictly increasing in  $\delta_{\eta,i}$ : Otherwise (when  $\delta_{\eta,-i} > 0$ ), anticipated utility is non-monotonic in  $\delta_{\eta,i}$ : there exists some  $\bar{\delta}_\eta$  such that for all  $\delta_{\eta,i} < \bar{\delta}_\eta$  anticipated utility is decreasing in  $\delta_{\eta,i}$  while for all  $\delta_{\eta,i} > \bar{\delta}_\eta$  it is increasing.*

As with beliefs about price information (i.e.,  $\delta_{z,i}$ ), anticipated utility is generically non-monotonic in the investor's perception of its informativeness (i.e.,  $\delta_{\eta,i}$ ). Moreover, this non-monotonicity is driven by the same channels. There is an (i) information channel, in which learning from the public signal reduces the conditional variance  $\text{var}_i[F - P|s_i, P, s_q]$  and a (ii)

speculative channel, in which a more informative public signal increases the precision of other investors’ beliefs, lowering potential speculative trading gains. Note, however, that when all other investors ignore the information in a public signal, it becomes effectively private for investor  $i$  — in this case, the information effect dominates because the speculative effect is zero, and anticipated utility is strictly increasing in  $\delta_{\eta,i}$ .<sup>29</sup>

Finally, we can characterize the equilibrium optimal beliefs which arise with any well-behaved cost function.

**Proposition 7.** *Suppose the cost function  $C(\delta_{e,i}, \delta_{z,i}, \delta_{\eta,i})$  is well-behaved. In any symmetric equilibrium, all investors are (weakly) over-confident about their private signal (i.e.,  $\delta_{e,i} \geq 1$  for all  $i$ ), choose to under-react to the information in prices (i.e.,  $\delta_{z,i} < 1$  for all  $i$ ), but choose to over-react to the information in the public signal (i.e.,  $\delta_{\eta,i} > 1$  for all  $i$ ).*

Though all investors observe the price and the public signal, they respond to the information in each source very differently: in any symmetric equilibrium, investors under-react to information in price, but overreact to the public signal. At any proposed symmetric equilibrium, we show that an investor’s anticipated utility increases when she believes that the public signal is more informative. As a result, the equilibrium choice of  $\delta_{\eta,i}$  cannot be lower than one: for any proposed equilibrium with  $\delta_{\eta,i} < 1$ , an investor can increase her anticipated utility and lower her costs by believing the price is more informative. This logic is similar to that which follows Proposition 3 explaining under-reaction to prices, but with the relative effect of the two channels flipped. Intuitively, believing that the price is more informative has a direct impact on the speculative opportunity, while believing that the public signal is more informative alters the investor’s perceived trading gains indirectly through the actions of other investors. This indirect channel is always dominated by the information channel, and so investors choose to overreact to the public signal but not to prices.

### B.3 Bounded variance

In the main text of the paper, we allow  $\delta_{z,i}$  to be any non-negative, real number. In Appendix B.1, we motivate this choice through a model of beliefs about others’ signals. As a result, an agent’s belief about the variance of the price is also unbounded. In what follows, we numerically establish the robustness of our results in a setting where this variance has an upper bound.

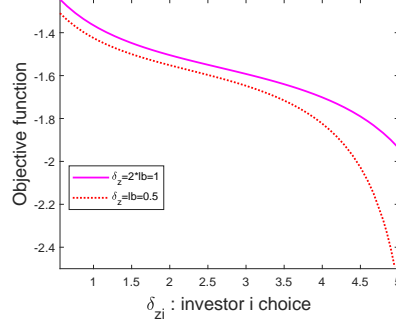
To see how such a bound might arise, we extend the setting introduced in the previous

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<sup>29</sup>This is similar to the effect found in Myatt and Wallace (2012), whereby acquiring more information from a public source is private information unless all other investors’ condition on the same “public” information.

Figure 5: Anticipated utility net of costs versus  $\delta_{zi}$

The figure plots the anticipated utility net of costs for investor  $i$  as a function of her choice of  $\delta_{zi}$ . Other parameters are:  $\tau = \tau_e = 1; \tau_z = 1; \gamma = 2$ .



section. If agents are constrained in their beliefs so that  $\pi_i = 1$ , then

$$\delta_{zi} \in \left[ \frac{\frac{\beta^2 \psi^2}{\tau_z}}{\frac{1}{\tau_e} + \frac{\beta^2}{\tau_z}}, \infty \right]$$

where the lower bound  $\frac{\beta^2 \psi^2}{\frac{1}{\tau_e} + \frac{\beta^2}{\tau_z}} < \psi^2 < 1$ . We numerically verify that the baseline model's main results still arise:

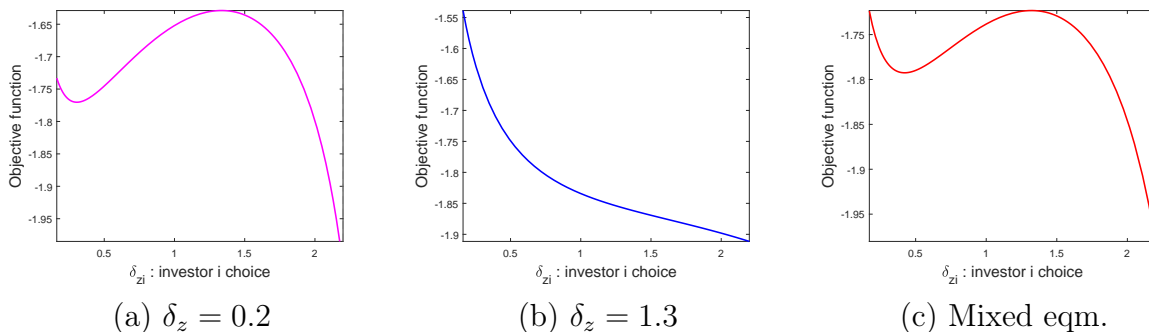
1. When risk aversion is sufficiently high, there exists a symmetric equilibrium in which all investors choose to set  $\delta_{zi}$  at the lower bound i.e.,  $\delta_{zi} = \frac{\beta^2 \psi^2}{\frac{1}{\tau_e} + \frac{\beta^2}{\tau_z}} < 1$ . In the baseline model, this is equivalent to choosing  $\delta_{z,i} = 0$  for all agents.
2. When risk aversion is sufficiently low, a symmetric equilibrium does not exist and investors endogenously separate into two groups: for the first group,  $\delta_{z,i} = \frac{\beta^2 \psi^2}{\frac{1}{\tau_e} + \frac{\beta^2}{\tau_z}} < 1$  and for the second group  $\delta_{z,i} > 1$ .

The following plots confirm these predictions. Figure 5 shows investor  $i$ 's objective as a function of  $\delta_{z,i}$ , for a given  $\delta_z$ , chosen by all other agents in the economy, and under the assumption that risk aversion is "high". The lower bound of  $\delta_{z,i}$  for the parameters chosen is 0.5. When all investors chose  $\delta_z = 1$  (solid line), investor  $i$  prefers to deviate and choose  $\delta_{z,i} = 0.5$ . When all other investors choose  $\delta_z = 0.5$ , investor  $i$  also chooses  $\delta_{z,i} = 0.5$ . Hence  $\delta_{z,i} = 0.5 \forall i$  is a symmetric equilibrium.

Figure 6 shows investor  $i$ 's objective in the case of low risk aversion. For the parameters chosen,  $\delta_z \in [0.16, \infty]$ . In panel (a), all other investors choose  $\delta_z = 0.16$ . In this case, investor  $i$  has an incentive to deviate by over-weighting the information in prices (i.e., by setting  $\delta_{z,i} \approx 1.3$ ). Even though the price is objectively very informative (the information

Figure 6: Anticipated utility net of costs versus  $\delta_{z,i}$

The figure plots the anticipated utility net of costs for investor  $i$  as a function of her choice  $\delta_{z,i}$ . Other parameters are:  $\tau = \tau_e = \tau_z = \delta_e = \delta_{e,i} = 1$ ,  $\gamma = 0.3$



channel), because other investors are placing low weight on it ( $\delta_z = 0.16$ ), the speculative effect of overweighting the price is relatively small. In panel (b), we consider an alternative symmetric equilibrium in which all other investors choose  $\delta_z = 1.3$ . Now, the speculative effect dominates and investor  $i$  strictly prefers to underweight the information in prices (i.e.,  $\delta_{zi} = 0.16$ ). In both cases, a symmetric equilibrium is ruled out because an individual investor has an incentive to deviate from the equilibrium behavior. Panel (c) of Figure 6 illustrates an instance of the asymmetric equilibrium. In this case, each investor is indifferent between two (sets of) beliefs.

## B.4 Ex-post belief choice

In the baseline model, we assumed that investor  $i$  chooses subjective beliefs  $(\delta_{ei}, \delta_{zi})$  before he/she observes the realization of the signals. In this section, we relax this assumption and assume that investor  $i$  can choose the subjective beliefs after she observes the realization of the signals. The anticipated utility, conditional on  $P$  and  $s_i$  is given by

$$AU_i(\delta_{e,i}, \delta_{z,i}; s_i, P) = -\exp\left\{-\frac{1}{2}\omega_i(\mu_i - P)^2\right\}.$$

Assuming that the cost function is well-behaved as defined in 1, the investor's objective function is to choose  $\delta_{e,i}, \delta_{z,i}$  by maximizing the anticipated utility, net of costs i.e.,

$$\max_{\delta_{e,i}, \delta_{z,i}} AU_i(\delta_{e,i}, \delta_{z,i}; s_i, P) - C_{obj}(\delta_{e,i}, \delta_{z,i}).$$

Note that

$$\begin{aligned} \frac{\partial}{\partial \delta_{e_i}} AU_i &\propto (\mu_i - P) \times [2\tau (s_i - m) + \omega_i (\mu_i - P)] \\ &\propto \left( s_i + \frac{B_i - \Lambda}{A_i} s_p \right) \left( s_i + \frac{B_i - \Lambda}{A_i + 2\frac{\tau}{\omega_i}} s_p \right) > 0 \iff s_i > \bar{s} \text{ or } s_i < \underline{s}. \end{aligned}$$

This implies that anticipated utility increases in  $\delta_{e,i}$  iff the private signal is either too high or too low. This implies that for extreme realizations of investors' private signals, the investor will be have incentive to be overconfident and for low realizations of investors private signals, the investors have an incentive to be under-confident. This is consistent with the results found in Ortoleva and Snowberg (2015) that overconfidence leads to ideological extremes.

Similarly,

$$\begin{aligned} \frac{\partial}{\partial \delta_{z_i}} AU_i &\propto (\mu_i - P) \times \{2\tau (s_p - m) + \omega_i (\mu_i - P)\} \\ &\propto \left( s_i + \frac{B_i - \Lambda}{A_i} s_p \right) ((B_i \omega_i + 2\tau) s_p + \omega_i (A_i - \Lambda) s_i) \\ &< 0 \iff s_i > \bar{S} \text{ or } s_i < \underline{S}. \end{aligned}$$

This again implies that for extreme realizations of private signals, an investor has an incentive to dismiss others' information. Moreover, for low absolute realizations of private signals, investors have an incentive to put more weight on the information found in the price.

Taken together, these results imply that for extreme realizations of private signals, investors will overweight private information and underweight price information i.e., the base-line results in the paper are robust for sufficiently extreme realizations of private signals. On the other hand, for moderate realizations of private signals, investors choose to underweight private information and overweight price information.