Uncertainty about What's in the Price

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Abstract

A critical question facing speculators contemplating to trade on private information is whether their signal has already been priced in by the market. In our model, speculators assess the novelty of their information based on recent price movements, and market makers are aware that speculators might be trading on stale news. An asymmetric response to past price movements ensues: after price increases, buy volume—because it may result from stale news trading—has a lower price impact than sell volume (and vice versa after price decreases). Consequently, return skewness is negatively related to lagged returns. We find strong support for these and other predictions using a comprehensive sample of US stocks.

JEL classification: G11, G14

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1 Introduction

Asset prices reflect information. Yet, in a complex world it is seldom clear *whether* a given piece of information is already reflected in the price or not. While there is a large literature on information asymmetry, informed trading, and learning from prices (e.g., Grossman, 1976; Grossman and Stiglitz, 1980; Hellwig, 1980; Kyle, 1985), this type of uncertainty is rarely captured in existing models. Indeed, almost all of the theoretical literature on this subject relies on an arguably implausible degree of common knowledge about the information structure faced by market participants. For example, it is typically assumed that all market participants know what type of signals, if any, are observed by *all* other market participants.[1] In practice, however, uncertainty about a stock is multidimensional and may depend on a variety of factors such as consumer demand, competition, takeover opportunities, technological changes, regulation etc. Given this complexity, it seems unrealistic that all investors know precisely how many other investors have information about each and every one of these dimensions of uncertainty. In other words, the assumption of complete knowledge of a stock's information environment—although common in the literature—is surely too restrictive.

This paper belongs to a nascent literature attempting to relax this restrictive common knowledge assumption. Prior work in this field has mostly looked at the asset pricing implications of the uncertainty that results when *uninformed* investors are not sure about the presence of informed investors (and thus about the importance of adverse selection). In contrast, this paper focuses on the uncertainty faced by *informed* investors about how informed they really are: do they possess genuinely novel information—on which it would be profitable to trade—or do they possess *stale* information that is already reflected in the price? Such type of uncertainty is very common. After

[1] For instance, in Grossman and Stiglitz (1980), investors are assumed to know both the *exact fraction* of informed and uninformed investors as well as *what* the informed investors are informed about (i.e., the fundamental is $u = \theta + \epsilon$ and informed investors are assumed to know θ).

all, prices can move for a myriad of reasons and it is difficult, nay impossible, for investors to know the precise extent to which a recent price move is driven by this or that piece of information. Hence, when investors contemplate trading on a signal, they will not know how many other investors have traded on this information before and thus how novel their signal truly is. In this paper, we put forth a parsimonious trading model in which investors face this type of uncertainty and describe the resulting equilibrium implications.

Two key insights emerge from the model. The first insight concerns investors' updating and was first pointed out by Treynor and Ferguson (1985) (albeit not in an equilibrium framework): investors rely on past price movements to assess the novelty of their trading signals.[2] To see the intuition for this, consider an investor that has just unearthed positive information about a stock. Not knowing whether this information is already reflected in the price or not, the investor looks at recent price changes for guidance. If the stock price has just gone up, it is possible that other investors have learned the same information before him, implying that his information is stale. In contrast, if the stock price has gone down, the price movement must be explained by some different information, and so the investor concludes that his information is novel. These considerations lead the investor with positive news to trade more (less) aggressively after recent price downturns (upturns).

The second insight involves market makers' assessment of adverse selection risk and is, to the best of our knowledge, new to the literature: after recent price increases (decreases), market makers consider positive (negative) order flow to be less informative, because it could come from investors trading on stale news, and so moderate its price impact. It follows that the skewness of returns depends negatively on lagged returns. Indeed, after price increases, market makers lower prices more in response to sell orders than they raise them in response to buy orders. Moreover, because speculators might actually be trading on stale (positive) news, buy orders are more likely than sell

[2] Treynor and Ferguson (1985) make this point in defense of technical analysis. In their study, they take prices as given and do not spell out the equilibrium implications of such behavior.

orders after price increases. Both effects contribute to making returns more negatively skewed. Conversely, returns are more positively skewed after price decreases, both because market makers raise prices more in response to buy orders than they reduce them in response to sell orders, and because buy orders are less likely. Hence our model predicts that equilibrium prices, return skewness, and trading strategies are asymmetric across buy and sell orders and depend on prior price movements. Our final implication is that, by making investors reluctant to trade on their information, uncertainty about what's in the price reduces the information content of stock prices.

We argue that the type of asymmetric dependence which we describe here arises naturally when there is uncertainty about what's in the price, making it a distinct "footprint" to look for in empirical data. Indeed, the literature to date has primarily focused on two different sources of asymmetry in price impact. The first is dynamic speculation (e.g., Llorente et al., 2002): when informed investors gradually establish their positions, a string of orders in the same direction signals their presence, prompting market makers to increase price impact. The second is inventory risk (e.g., Ho and Stoll, 1981; Madhavan and Smidt, 1993; Hendershott and Menkveld, 2014): when market makers are loath to deviate from a given target inventory level, they require bigger price concessions for accommodating orders that push their inventory further away from target as compared to orders that allow them to move toward the target. In both cases, buy (sell) orders that come after buy orders are associated with a larger (lower) price impact. Our model makes the exact opposite prediction: buy orders that come after prior buy orders are less informative (since they could come from speculators trading on stale news), implying a lower price impact. In practice, all of these channels are expected to co-exist. It is thus an empirical question whether our prediction regarding uncertainty about what's in the price prevails in the data.

We shed light on this question by examining an exhaustive sample of NYSE-traded stocks from 1993 to 2014. Starting with skewness, we find that the daily skewness of stock returns (estimated from intraday TAQ data) is negatively related to lagged returns, consistent with the model. This phenomenon is economically meaningful, as a one-standard deviation (1-SD) increase in lagged returns decreases skewness by about 12% of a SD. Moreover, in contrast to alternative mechanisms (discussed below) that rely on short sale constraints, this relationship holds for both positive and negative lagged returns, and is insensitive to short selling costs (which proxy for the tightness of short sale constraints). Turning to the price impact predictions, we compare price impact costs on days with net-buying and net-selling activity as a function of past returns. Using the Lee and Ready (1991) algorithm to infer trade direction, we compute daily measures of trade imbalances from intraday TAQ data. We document that, on days with net-buying activity, price impact costs (measured using four distinct proxies that reflect adverse selection) are negatively related with past returns, while on days with net-selling activity price impact costs are positively related with past returns.[3] Put differently, buys elicit a lower price impact when prior returns were positive, consistent with market makers understanding that investors are potentially buying based on stale news; for the same reason, sells elicit a lower price impact when prior returns were negative. This phenomenon is again economically meaningful. For instance, a 1-SD increase in lagged returns decreases (increases) price impact costs on days with a positive (negative) trade imbalance by about 6% of a SD, thus driving a wedge between buy- and sell-days of about 12% of a SD.

In our model, asymmetric patterns in skewness and price impact arise only when there is uncertainty about what's in the price. We therefore check whether our previous findings weaken when uncertainty about what's in the price is arguably lower. We report two sets of results. First, we find that the asymmetric patterns in skewness and price impact are considerably less pronounced immediately after earnings announcements, when investors know better what information is already impounded in stock prices.

[3]Our four price impact measures are: i) a signed version of the Amihud (2002) illiquidity ratio, named *price impact costs*, defined as the ratio of a stock's daily return (adjusted for autocorrelation) over its signed trade imbalance; ii) *lambda*, the slope coefficient from a regression of stock returns on signed order flow over five-minute intervals; iii) *quote-based price impact*, the percentage change in the mid-quote from before to five minutes after the transaction; iv) *ln(Amihud)*, the standard Amihud (2002) illiquidity ratio, defined as the logarithm of the stock's absolute return divided by its dollar volume.

Second, they are weaker for stocks for which more information is public; that is, for larger stocks and stocks with more analyst coverage. These tests confirm that non-public information—i.e., information whose degree of common knowledge is hard to ascertain—plays a central role in the phenomena we document.

Finally, we assess the implication of the model for stock price informativeness. To do so, we construct a cross-sectional measure of the extent of uncertainty about what's in the price based on the sensitivity of return skewness with respect to past returns—the more negative this sensitivity, the higher the uncertainty. We then relate this measure to the information content of prices around earnings announcements. Following Weller (2018), we construct a measure of stock price informativeness—called the price jump ratio—defined as the fraction of the total earnings-related return change that occurs at the announcement. The higher this measure, the less information has entered stock prices before the announcement, indicating lower price informativeness. We find that heightened uncertainty about what's in the price is consistently associated with a higher jump price ratio and thus with less informative stock prices. This confirms our model prediction that investors concerned about the novelty of their signals trade more cautiously and thereby slow down the capitalization of information into stock prices.

Overall, our results indicate that uncertainty about what's in the price is a genuine concern for investors. Indeed, we are not aware of any other theory that *jointly* explains: 1) why return skewness depends negatively on past price movements; 2) why price impact costs depend on past price movements asymmetrically across buy and sell orders; 3) why the dependence of both return skewness and price impact costs is consistently reduced after public announcements and for stocks in the limelight; and finally 4) why stock price informativeness is negatively affected by this dependence.

Related literature. Our paper contributes primarily to the theoretical literature on informed trading in financial markets, and more specifically, to the body of research relaxing the assumption that investors' information environment is common knowledge. Prior work finds that under multidimensional uncertainty—such as when the proportion of informed traders is unknown—traders might ignore their own information or delay acting on it, leading to herding (Avery and Zemsky (1998)) or to persistent mispricing (Abreu and Brunnermeier, 2002; Abreu and Brunnermeier, 2003). More recently, Gao et al. (2013), Banerjee and Green (2015), and Papadimitriou (2020) study traders who are uncertain about the proportion of informed traders. In Banerjee and Green (2015) in particular, learning about whether others are trading on informative signals or noise leads to prices that react asymmetrically to news about fundamentals and hence to returns that depend asymmetrically on lagged returns (as explained below, the asymmetry is different from what is predicted by our model). In Easley and O'Hara (1992), market makers are unsure whether speculators have observed a signal about the asset's fundamental. Importantly, the learning agents in all these papers are themselves uninformed; hence, they cannot use their own signal realization in combination with the price to update their beliefs about the information structure of the market. It is this interplay between an investor's own signal realization and recent price changes that lies at the heart of our model. Another line of research (Blume et al., 1994; Schneider, 2009) studies investors' use of trading volume data to learn about properties of other investors' private signals (i.e., their precision or correlation with other investors' signals). In contrast, our focus is on how investors use (endogenous) past price movements to determine the extent of their information advantage and their optimal trading intensity.

Our paper also relates to three other streams of research. The first is the literature on "technical analysis" (e.g., Brown and Jennings, 1989; Grundy and McNichols, 1989; Brunnermeier, 2005). In these models, past prices have an *independent* signal value that is not subsumed by the current price, but the information structure remains common knowledge. Investors are therefore not worried that their signals may be stale; they simply use past prices to try to obtain a better estimate of the signal realizations observed by other investors. In our model, in contrast, investors use them to update on the probability that others have seen the same information before them (thereby rendering their signal stale). Because this behavior is anticipated by market makers, prices respond asymmetrically to positive and negative order flow as a function of past price movements. Saar (2001) makes a similar prediction in a model that preserves the common knowledge assumption but relies instead on a set of portfolio constraints that typically apply to mutual funds. Specifically, he assumes that informed investors cannot borrow, sell short, nor underdiversify (i.e., concentrate holdings on only a few stocks). After the price increases (decreases), informed traders are more (less) likely to own the stock—since they probably bought (sold) the stock on the past good (bad) news that increased (decreased) the price; as a result, their buys (sells) are more constrained by the diversification (short sale) constraint, reducing the information content of the buy (sell) order flow. Our mechanism does not rely on portfolio or short sale constraints (which are presumably less binding for informed traders such as hedge funds than for mutual funds); instead it follows from a relaxation of the (arguably unrealistic) common knowledge assumption. Empirically, we document that our findings are not driven by short sale constraints.[4]

Second, our paper contributes to the literature on stock return skewness. While this literature spans many aspects, our contribution is to shed light on the determinants of individual stock return skewness, and more specifically, on how it depends on past price movements. Prior research finds that return skewness is negatively related to lagged returns (e.g., Harvey and Siddique, 2000; Chen et al., 2001), but is less clear on the mechanism underlying this relationship. Prominent theories rely on the existence of bubbles (which build up and eventually burst) or on the combination of differences of opinions with short sale constraints (which temporarily prevent bearish information from being fully incorporated into prices; Chen et al., 2001). While these theories explain why skewness is more negative after high past returns, they fail to account for the symmetric phenomenon—which we find to be equally strong in the data—that skewness is more positive after low past returns.[5] Our model offers a parsimonious explanation

[4]Specifically, we find that the dependence of return skewness and price impact costs on past returns does not strengthen when shorting fees (a proxy for the tightness of the constraint) are higher, see Section 3.4 for a detailed discussion.

[5]One exception is Xu (2007), who presents a model in which short sale-constrained investors disagree

for these patterns by merely requiring (fully rational) investors to be uncertain about how informed they really are. To be clear, our intention in this paper is to highlight that the dependence of skewness and price impact costs on past returns is multi-faceted, rather than to dismiss alternative mechanisms. More work is needed to ascertain the relative importance of each channel and the conditions under which they prevail.

Finally, our paper is also related to the empirical literature on stale news trading (e.g., Huberman and Regev, 2001; Tetlock, 2011; Gilbert et al., 2012). While these papers point to attention constraints or to an irrational overreaction to news, we argue that even sophisticated investors may find it difficult to judge the true value of a privately-acquired signal and may end up trading on stale information. We explore the ramifications of this idea in a model that is a entirely rational (apart from the usual assumption about noise trading) and shed a first light on its empirical relevance.

The paper proceeds as follows. Section 2 describes a simple trading game and solves it under different assumptions about the information structure, before discussing the distinct predictions that result from uncertainty about what's in the price. Section 3 presents empirical tests of of our model predictions regarding return skewness, price impact costs, and stock price informativeness. Section 5 concludes.

2 Model

We develop a parsimonious model in which investors face uncertainty about what's in the price. We deliberately keep our model as simple as possible for ease of exposition.

2.1 Setup

There are three dates, denoted 0, 1, and 2; three categories of agents, namely market makers, speculators (or insiders), and noise traders; and a single stock. The stock pays

on the precision of a publicly observed signal. We find no evidence that the return-skewness relationship strengthens when shorting is more costly, contrary to what Xu (2007) implies. Moreover, his model predicts that the relationship should be weaker after public news announcements. We find the opposite in our data.

a dividend of $\theta = \theta_1 + \theta_2$ at date $t = 2$, where θ_1 and θ_2 are independent and both pay off $+\sigma$ or $-\sigma$ with equal probability. Hence, θ is -2σ with probability 1/4, 0 with probability 1/2, or $+2\sigma$ with probability 1/4.

At dates $t = 0$ and $t = 1$, prices are set by competitive market makers (henceforth M) as in Kyle (1985). At date $t = 0$, there are no speculators and no noise traders. Market makers observe a part of the fundamental θ_m where $m \in \{1, 2\}$ with equal probability, and equate the price of the asset, p_0, to their expectation of the dividend: $p_0 = E(\theta|\theta_m) = \theta_m$. At date $t = 1$, a unit-mass of informed speculators (henceforth S) with mean-variance utility and risk aversion parameter γ all observe the same part of the fundamental θ_s where $s \in \{1, 2\}$ with equal probability. They then submit market orders conditional on the realization of their signal and the price at $t = 0$, p_0 (that is, θ_m).[6] The variables m and s are drawn independently, implying that M and S observe with equal probability the same part of the fundamental ($m = s$) or different parts ($m \neq s$). At date $t = 1$, there are also noise traders who submit a random market order, n, uniformly distributed over the interval $[-1, +1]$. Therefore, the total order flow at date $t = 1$, ω_1, consists of the orders of the speculators and of the noise traders.

We assume that speculators are sufficiently risk averse and/or that fundamental uncertainty is high enough. This assumption ensures that the aggregate order flow at $t = 1$ is not fully revealing (which would render the model uninteresting):

Assumption 1. *Let $\gamma\sigma > 3$.*

Our way of modeling the stock dividend as being determined by two parts, θ_1 and θ_2, captures in stylized fashion the idea that a stock's fundamental value depends on multiple sources uncertainty. Which bits and pieces are known to M and S, respectively, and whether they know what the others know are central elements to the model. Figure 1 summarizes the model setup.

[6]The assumption that all speculators observe the same part of the fundamental is not crucial for our argument. Indeed, the model's main prediction about investors' updating on the novelty of their signal based on past price movements remains valid if one, for example, assumes that each speculator i observes θ_{s_i} with $s_i \in \{1, 2\}$ being independent from m and s_j for all speculators $j \neq i$.

2.2 Benchmark: No uncertainty about what's in the price

We describe a benchmark in which speculators face no uncertainty about what's in the price. We first assume that both speculators and market makers know which component of the fundamental the other group observes. Then we assume that only market makers face uncertainty about what's in the price; that is, speculators know which component market makers observe, but not vice versa.

2.2.1 Both m and s are common knowledge

We start by assuming that both M and S know m and s. That is, both M and S know which part of the fundamental is observed by M at $t = 0$ and whether S have observed the same part or not. Consider first the case $m = s$, meaning that both M and S know the same part of the fundamental, $\theta_m = \theta_s$. S then have no information advantage over M and thus refrain from trading ($\omega_1 = n$). Therefore, $p_0 = p_1 = \theta_m$.

Next, suppose M and S observe different parts of the fundamental; that is, $m \neq s$. In this case, M do not know the exact realization of θ_s, but they know that S have an information advantage (since they also observe $p_0 = \theta_m$) they will trade on. M then try to back out θ_s from the order flow. We conjecture that S trade in a symmetric fashion and buy $x_{(1)}$ (sell $-x_{(1)}$) with $|x_{(1)}| < 1$ when they know $\theta_s = \sigma$ ($\theta_s = -\sigma$). Hence, the order flow is $\omega_1 = x_{(1)} + n$ if $\theta_s = \sigma$, and $\omega_1 = -x_{(1)} + n$ if $\theta_s = -\sigma$. If M observe $\omega_1 > -x_{(1)} + 1$ ($\omega_1 < x_{(1)} - 1$), then they infer that $\theta_s = \sigma$ ($\theta_s = -\sigma$). If instead $x_{(1)} - 1 \leq \omega_1 \leq -x_{(1)} + 1$, then it is both possible that S bought or sold and M learn nothing about θ_s. Accordingly, the equilibrium price is given by:

$$p_1 = \begin{cases} \theta_m + \sigma & \text{for} \quad -x_{(1)} + 1 < \omega_1 \leq x_{(1)} + 1 \\ \theta_m & \text{for} \quad x_{(1)} - 1 \leq \omega_1 \leq -x_{(1)} + 1 \\ \theta_m - \sigma & \text{for} \quad -x_{(1)} - 1 \leq \omega_1 < x_{(1)} - 1 \end{cases}$$

Each speculator i from the set S chooses her order x_i to maximize expected utility, taking the price function as given. Imposing rational expectations (i.e., $x_i = x_{(1)}$ for all i in S) on the first-order condition yields the following equilibrium condition:

$$x_{(1)} = \frac{E\left[\theta - p_1 \,|\, p_0, \theta_s\right]}{\gamma Var\left[\theta - p_1 \,|\, p_0, \theta_s\right]}$$

Consider the case $m \neq s$ and $\theta_s = \sigma$ (the case $\theta_s = -\sigma$ is symmetric). We have $E\left[\theta - p_1 \,|\, p_0, \theta_s = \sigma, m \neq s\right] = \sigma(1 - x_{(1)})$ and $Var\left[\theta - p_1 \,|\, p_0, \theta_s = \sigma, m \neq s\right] = \sigma^2 x_{(1)}(1 - x_{(1)})$. Plugging these expressions into the previous equation yields $x_{(1)} = \sqrt{1/(\gamma\sigma)}$. The following proposition summarizes the equilibrium.

Proposition 2. *Assume that market makers M and speculators S know which part of the fundamental is observed by M and S; that is, m and s are common knowledge. At $t = 0$, M set $p_0 = \theta_m$. At $t = 1$:*

- *If $m = s$, then S refrain from trading, and M set $p_1 - p_0 = 0$.*
- *If $m \neq s$ and $\theta_s = \sigma$ ($\theta_s = -\sigma$), then S buy (sell) an amount $x_{(1)}$ ($-x_{(1)}$) where $x_{(1)} = \sqrt{1/(\gamma\sigma)}$. M set the price change, $p_1 - p_0$, independently of the realization of p_0, according to:*

$$p_1 - p_0 = \begin{cases} +\sigma & \textit{for} \quad -x_{(1)} + 1 < \omega_1 \leq x_{(1)} + 1 \\ 0 & \textit{for} \quad x_{(1)} - 1 \leq \omega_1 \leq -x_{(1)} + 1 \\ -\sigma & \textit{for} \quad -x_{(1)} - 1 \leq \omega_1 < x_{(1)} - 1 \end{cases} \tag{1}$$

Intuitively, speculators S trade less aggressively ($x_{(1)}$ lower) when they are more averse to risk (γ larger) and when the final payoff is more uncertain (σ larger). Note that $x_{(1)} < 1$ by Assumption 1, and hence the order flow $\omega_1 = x_{(1)} + n$ does not fully reveal θ_s, implying that S derive positive expected utility from trading. The solution resembles Vives (1995), who also models trading by a continuum of risk-averse speculators in the presence of competitive market makers (but with normally-distributed payoff and noise). The key feature of the equilibrium is that the price change, $p_1 - p_0$, does not depend on the lagged price p_0; that is, a buy or sell order triggers a price change of the same magnitude regardless of the lagged price.

2.2.2 Only m is common knowledge

We now assume that S know m and s, but that M only know m. In other words, both M and S know which part of the fundamental is observed by M (and thus reflected in p_0), but only S know whether they observed the same part or not. In essence, this setting features uncertainty for market makers about whether (better) informed speculators are present or not.

If M and S observe the same part of the fundamental (i.e., $m = s$), then S have no information advantage over M and thus refrain from trading ($\omega_1 = n$). If $m \neq s$, then S have additional information about θ and are conjectured to buy (sell) an amount $x_{(2)}$ ($-x_{(2)}$) when $\theta_s = \sigma$ ($\theta_s = -\sigma$). Market makers M do not know, however, which of these cases has occurred and try to learn from the order flow. If M observe $\omega_1 > 1$ ($\omega_1 < -1$), then they infer that $\theta_s = \sigma$ ($\theta_s = -\sigma$). If $-x_{(2)} + 1 \leq \omega_1 \leq 1$ ($-1 \leq \omega_1 < x_{(2)} - 1$), then M know that S did not sell $-x_{(2)}$ (did not buy $x_{(2)}$). In other words, M know that either $m = s$ (when S do not trade) or $\theta_s = \sigma$ ($\theta_s = -\sigma$). The conditional expectation of θ_s is then $\frac{1}{3}\sigma$ ($-\frac{1}{3}\sigma$) (see Appendix A.2). Finally, if $x_{(2)} - 1 \leq \omega_1 \leq -x_{(2)} + 1$, then M learn nothing about θ_s. Therefore, the equilibrium price function is given by Equation (2) below.

Given this price function, S choose the order size x that maximize their expected utility. Consider the case when $m \neq s$ and they know $\theta_s = \sigma$ (the case $\theta_s = -\sigma$ is symmetric). In this case, S are expected to buy, implying that the order flow is drawn at random from the interval $[x_{(2)} - 1, x_{(2)} + 1]$. It follows that (see Appendix A.2):

$$\begin{aligned} E(\theta - p_1|p_0, \theta_s = \sigma, m \neq s) &= \sigma\left(1 - \frac{2}{3}x_{(2)}\right) \\ Var(\theta - p_1|p_0, \theta_s = \sigma, m \neq s) &= \sigma^2 x_{(2)}\left(\frac{5}{9} - \frac{4}{9}x_{(2)}\right) \end{aligned}$$

Plugging these expressions into the first-order condition for S' profit maximization problem and imposing rational expectations (i.e., $x_i = x_{(2)}$ for all i in S) yields the optimal order size $x_{(2)}$. The following proposition summarizes the resulting equilibrium.

Proposition 3. *Assume that only m is common knowledge; that is, speculators S know which part of the fundamental is observed by market makers M but not vice versa. At $t = 0$, M set $p_0 = \theta_m$. At $t = 1$:*

- *If $m = s$, then S refrain from trading.*
- *If $m \neq s$ and $\theta_s = \sigma$ ($\theta_s = -\sigma$), then S buy (sell) an amount $x_{(2)}$ $(-x_{(2)})$, where $x_{(2)}$ is defined in Appendix A.2.*

Market makers M don't know whether $m = s$ or $m \neq s$ and set the price change, $p_1 - p_0$, independently of the realization of p_0, according to:

$$p_1 - p_0 = \begin{cases} +\sigma & \text{for} \quad 1 < \omega_1 \leq x_{(2)} + 1 \\ +\frac{1}{3}\sigma & \text{for} \quad -x_{(2)} + 1 < \omega_1 \leq 1 \\ 0 & \text{for} \quad x_{(2)} - 1 \leq \omega_1 \leq -x_{(2)} + 1 \\ -\frac{1}{3}\sigma & \text{for} \quad -1 \leq \omega_1 < x_{(2)} - 1 \\ -\sigma & \text{for} \quad -x_{(2)} - 1 \leq \omega_1 < -1 \end{cases} \tag{2}$$

Proof. See Appendix A.2. □

As before, the equilibrium trading aggressiveness, $x_{(2)}$, is decreasing in γ and σ. Hence, S trade less aggressively when they are more risk averse or when the stock's payoff is more uncertain. Importantly, the price change, $p_1 - p_0$, again does not depend on the lagged price p_0. As we shall see, this is no longer the case when speculators face uncertainty about what's in the price.

We briefly compare this version of the model to Banerjee and Green (2015), who also solve a rational expectation equilibrium model in which there is uncertainty about whether informed traders are present or not. One key difference is that here prices are set by competitive market makers, whereas Banerjee and Green (2015) rely on market-clearing by risk-averse investors. Since in Banerjee and Green (2015) the asset is in positive supply, prices reflect a risk premium and an asymmetry emerges: both high and low price signals lead investors to update upward the probability that informed traders are present and thus command a larger price discount, which attenuates (resp. amplifies) the market response to positive (resp. negative) news. Market makers are risk-neutral in our model, so there is no such risk discount effect and the price function remains symmetric despite the uncertainty about whether there are informed traders. Instead, as we will see next, there emerges another type of asymmetry (whose nature changes with p_0) when there is uncertainty about what's in the price.

2.3 Uncertainty about what's in the price: Neither m nor s are common knowledge

We now tackle the case of interest—that is, the case in which speculators face uncertainty about whether their trading signals are already reflected in the price. Specifically, we assume that M know m and S know s, but neither group knows which part of the fundamental was observed by the other. That is, as in the model solution discussed in Section 2.2.2, M do not know whether S observed the same part of the fundamental or not, but now this uncertainty also extends to S. As a result, when S' signal coincides with the signal observed by M as revealed by the $t = 0$ price ($\theta_m = \theta_s$), then S are unsure whether they observed the same part of the fundamental or whether they actually observed the other part and it just happens that this news goes in the same direction. When $\theta_m \neq \theta_s$, however, then S infer that $m \neq s$ and they understand that they have truly novel information.

To solve for the trading equilibrium, we conjecture that S buy (sell) an amount $x_{(3)}$ ($-x_{(3)}$) when $\theta_m \neq \theta_s$ and that they buy (sell) an amount $y_{(3)}$ ($-y_{(3)}$) when $\theta_m = \theta_s$ with $x_{(3)} \geq y_{(3)}$. Consider the case $\theta_m = \sigma$. Given the conjecture, M expect S to either buy $y_{(3)}$ (when $\theta_s = \sigma$) or sell $-x_{(3)}$ (when $\theta_s = -\sigma$). If $-x_{(3)} + 1 < \omega_1 \leq y_{(3)} + 1$, then M infer that S bought y. Their expectation of the component of θ that they do not observe is then $\frac{1}{3}\sigma$ (see Appendix A.3), resulting in a price of $\sigma + \frac{1}{3}\sigma = \frac{4}{3}\sigma$. If $-x_{(3)} - 1 \leq \omega_1 < y_{(3)} - 1$, then M know that S sold $x_{(3)}$. Their expectation of the component of θ that they do not observe is therefore $-\sigma$ and so the price equals $\sigma - \sigma = 0$. If $y_{(3)} - 1 \leq \omega_1 \leq -x_{(3)} + 1$, then it is both possible that S bought or sold; thus M learn nothing from the order flow and maintain the price at σ, the realization of their signal θ_m. As a result, the price function is given by Equation (3) below. For the case $\theta_m = -\sigma$, the logic is reversed. S either buy $x_{(3)}$ or sell $-y_{(3)}$, and M draw analogous inferences from the order flow, leading to the price function (4).

The crucial feature of these price functions is their asymmetry: market makers anticipate that sell volume after a price increase is a more informative signal about the stock's fundamental compared to buy volume. The reason is that sell volume after a price increase indicates that speculators trade on genuine new information, whereas buy volume can also come from speculators trading on stale information (i.e., information already reflected in p_0). Hence, price impact is larger for sell (buy) volume after recent price increases (decreases).

We now solve for the equilibrium trading quantities, $x_{(3)}$ and $y_{(3)}$. Consider the case $\theta_m = -\sigma$ (as usual, the case $\theta_m = \sigma$ is symmetric), which is revealed to investors S by the $t = 0$ price. When $\theta_s = \sigma$, an investor i in set S expects the other investors in S to buy an amount $x_{(3)}$, resulting in an order flow drawn at random from the interval $[x_{(3)} - 1, x_{(3)} + 1]$. The investor then calculates (see Appendix A.3):

$$
\begin{aligned}
E(\theta - p_1|\theta_m = -\sigma, \theta_s = \sigma) &= = \sigma \left(1 - \frac{x_{(3)} + y_{(3)}}{2}\right) \\
Var(\theta - p_1|\theta_m = -\sigma, \theta_s = \sigma) &= \sigma^2 \left(1 - \frac{x_{(3)} + y_{(3)}}{2}\right) \frac{x_{(3)} + y_{(3)}}{2}
\end{aligned}
$$

When $\theta_s = -\sigma$, investors expect other investors in S to sell an amount $-y_{(3)}$, resulting in an order flow drawn at random from the interval $[-y_{(3)} - 1, -y_{(3)} + 1]$. The investor then calculates (see Appendix A.3):

$$
\begin{aligned}
E(\theta - p_1 | \theta_m = -\sigma, \theta_s = -\sigma) &= -\frac{1}{3}\sigma\left(1 - \frac{x_{(3)} + y_{(3)}}{2}\right) \\
Var(\theta - p_1 | \theta_m = -\sigma, \theta_s = -\sigma) &= \frac{1}{9}\sigma^2\left(8 + \frac{x_{(3)} + y_{(3)}}{2}\left(1 - \frac{x_{(3)} + y_{(3)}}{2}\right)\right)
\end{aligned}
$$

Investors first-order condition together with requiring rational expectations for the two cases $\theta_s = \sigma$ and $\theta_s = -\sigma$ (i.e., $x_i = x_{(3)}$ in the former case and $x_i = y_{(3)}$ in the latter) yields a system of two equations in $x_{(3)}$ and $y_{(3)}$. The following proposition summarizes the resulting equilibrium.

Proposition 4. *Assume that neither m nor s are common knowledge. At $t = 0$, market makers M set $p_0 = \theta_m$. At $t = 1$:*

- *If $\theta_m \neq \theta_s$ and $\theta_s = \sigma$ ($\theta_s = -\sigma$), then speculators S buy (sell) an amount $x_{(3)}$ ($-x_{(3)}$), where $x_{(3)}$ is defined in Appendix A.3.*
- *If $\theta_m = \theta_s$ and $\theta_s = \sigma$ ($\theta_s = -\sigma$), then S buy (sell) an amount $y_{(3)}$ ($-y_{(3)}$), where $y_{(3)} = \frac{2-\gamma\sigma x_{(3)}^2}{\gamma\sigma x_{(3)}} \leq x_{(3)}$.*

The price change, $p_1 - p_0$, depends on the realization of $p_0 = \theta_m$ as follows:

- *If $\theta_m = +\sigma$, then*

$$
p_1 - p_0 = \begin{cases} \frac{1}{3}\sigma & \textit{for} \quad -x_{(3)} + 1 < \omega_1 \leq y_{(3)} + 1 \\ 0 & \textit{for} \quad y_{(3)} - 1 \leq \omega_1 \leq -x_{(3)} + 1 \\ -\sigma & \textit{for} \quad -x_{(3)} - 1 \leq \omega_1 < y_{(3)} - 1 \end{cases} \tag{3}
$$

- *If $\theta_m = -\sigma$, then*

$$
p_1 - p_0 = \begin{cases} +\sigma & \textit{for} \quad -y_{(3)} + 1 < \omega_1 \leq x_{(3)} + 1 \\ 0 & \textit{for} \quad x_{(3)} - 1 \leq \omega_1 \leq -y_{(3)} + 1 \\ -\frac{1}{3}\sigma & \textit{for} \quad -y_{(3)} - 1 \leq \omega_1 < x_{(3)} - 1 \end{cases} \tag{4}
$$

Proof. See Appendix A.3. □

Both $x_{(3)}$ and $y_{(3)}$ are decreasing in γ and σ; that is, as in the previous cases, speculators trade more cautiously when they are more risk averse or when the stock's payoff is more uncertain. Moreover, since $x_{(3)} \geq y_{(3)}$ in equilibrium, investors trade more aggressively on their information when they are sure that it is novel as compared to the case when they are worried that market makers could have seen it first.

2.4 Comparison of equilibria

We now compare the equilibrium outcomes for the different degrees of common knowledge that we analyzed previously. For ease of reference, we refer to these equilibria as follows: the case with m and s being common knowledge (Section 2.2.1) is denoted by (1), the case with only m being common knowledge (Section 2.2.2) with (2), and the case of interest with neither m nor s being common knowledge (Section 2.3) with (3). We highlight that only equilibrium (3) displays uncertainty about what's in the price.

We begin by comparing the price functions that obtain in the three equilibria.

Corollary 5. *In equilibria (1) and (2), price impact costs for buys and sells are symmetric and do not depend on the previous price update. In equilibrium (3)—i.e., under uncertainty about what's in the price—price impact costs are asymmetric and depend on the previous price update: after a price increase (decrease), price impact costs for buys (sells) are reduced, while those for sells (buys) are increased.*

This corollary highlights the key distinguishing feature of the model with uncertainty about what's in the price: price impact costs differ for buys and sells as a function of past price movements, as illustrated in Figure 2. Intuitively, when buy (sell) volume follows a recent price uptick (downtick), market makers assign a positive probability to the possibility that speculators are trading on stale news and therefore charge a lower price impact.

The asymmetric price impact of Corollary 5 naturally leads to return skewness, with a sign that depends on the prior price change, as described next.[7]

Corollary 6. *In equilibria (1) and (2), return skewness is unrelated to the lagged return. In equilibrium (3)—i.e., under uncertainty about what's in the price—return skewness is negatively related to the lagged return.*

After price increases (decreases), market makers update prices more aggressively in response to incoming sell (buy) orders than to incoming buy (sell) orders, resulting in negatively (positively) skewed returns. Moreover, after price increases (decreases), speculators are more likely to buy (sell) as they may be trading on positive (negative) stale news. This further contributes to negatively (positively) skewed returns after price increases (decreases).

Finally, we examine the price informativeness for the three different equilibria. We define price informativeness as $PI \equiv Var\left(E\left(\theta|p_1, p_0\right)\right)$.[8] The higher this measure, the more information prices contain, which lowers the residual uncertainty faced by investors and—to the extent that prices convey information to real decision makers (see e.g. Luo, 2005; Chen et al., 2007; Foucault and Fresard, 2012; Dessaint et al., 2018)—promotes real efficiency.

Corollary 7. *The price informativeness in equilibria (1), (2), and (3) is as follows:*

$$
\begin{aligned}
PI_{(1)} &= \sigma^2\left(1+\frac{1}{2}x_{(1)}\right)\\
PI_{(2)} &= \sigma^2\left(1+\frac{1}{3}x_{(2)}\right)\\
PI_{(3)} &= \sigma^2\left(1+\frac{1}{6}\left(x_{(3)}+y_{(3)}\right)\right)
\end{aligned}
$$

Moreover, we have $PI_{(3)} < PI_{(2)}$ and $PI_{(3)} < PI_{(1)}$ (whereas the comparison between

[7]Our prediction on the skewness of price changes, $p_1 - p_0$, can be expressed using the skewness of returns, $(p_1 - p_0)/p_0$, since we compare prices across buy and sell orders starting from the same initial price, p_0.

[8]Alternatively, price informativeness can be defined as $E\left(Var\left(\theta|p_1, p_0\right)\right)$. The definitions are equivalent and related through the Law of Total Variance: $E\left(Var\left(\theta|p_1, p_0\right)\right) = Var\left(\theta\right) - Var\left(E\left(\theta|p_1, p_0\right)\right) = 2\sigma^2 - Var\left(E\left(\theta|p_1, p_0\right)\right)$.

$PI_{(1)}$ and $PI_{(2)}$ depends on the parameters).

The corollary shows that uncertainty about what's in the price unambiguously reduces price informativeness. There are two opposing effects that bear on price informativeness. On the one hand, when speculators are worried about whether their signal is stale, they trade less aggressively and thus impound less information into the price. On the other hand, compared to the case in which both speculators and market makers know s, speculators trade slightly more aggressively when they are sure that their signal is novel (i.e., when the signal goes against the most recent price change). This second effect is indirect and comes from lower price impact costs since—with uncertainty about what's in the price—market makers expect a less informative order flow on average. Overall, the direct effect outweighs the indirect one and so price informativeness decreases.

2.5 Discussion of model assumptions

Our model is deliberately kept as simple as possible. Nonetheless, we conjecture that the main intuition is robust to alternative assumptions.

First, we have assumed that market makers observe a part of the fundamental and set p_0 equal to their signal. This is just a convenient short cut. A more elaborate model would have different groups of speculators observing different or the same signals, and trading at different points in time. Such a model yields similar insights. The price at $t = 0$ reflects the signals of speculators trading in that period. As in our model, speculators arriving at $t = 1$ would then compare their signal realizations with p_0 in order to assess whether other speculators have already traded on the same signal before them.

Second, regarding the model's distributional assumptions, the two pieces of the fundamental value, θ_1 and θ_2, are assumed to follow binary distributions. This renders speculators' inference particularly simple: when their signal is "high" and the price is "low," speculators infer that the signal must be novel; when speculators' signal is "high" and the price is "high" as well, then speculators are unsure about whether their signal is novel or stale. This intuition carries over naturally to continuous random variables provided we add some noise to the price. To see this, suppose that θ_1 and θ_2 are drawn from continuous distributions and that the price at $t = 0$ reflects market makers' signal with noise.[9] This noise might stem from market makers observing a noisy signal of θ_s or from trading for reasons unrelated to the stock's fundamentals such as inventory concerns.[10] As before, speculators arriving at $t = 1$ compare their signal with p_0. If the distributions from which θ_1, θ_2, and noise n are drawn satisfy the *monotone likelihood ratio property* (as is the case for example with normal distributions), then speculators' inference depends monotonically on the *distance* between θ_s and p_0: the larger this distance, the more likely it is that their signal is novel. Our key model prediction about asymmetric price impact costs is expected to go through in this setup.

Third, trading on stale news occurs in our model despite all investors (speculators and market makers) being *rational*. Indeed, we think of this as the key contribution of our model: in a world with multidimensional uncertainty, even rational investors are unsure what news is priced in and, hence, may end up trading on stale news. In practice, some stale news trading may be due to (irrational) noise traders or feedback traders/trend chasers (e.g., Barber and Odean, 2007; Tetlock, 2011). Since price impact in our theory is caused by adverse selection, our model has nothing to say on the effect of stale news trading on other sources of illiquidity, such as inventory or noise trader risk (e.g., Grossman and Miller, 1988; Foucault et al., 2011; Hendershott and Menkveld, 2014; Peress and Schmidt, 2020).[11] Still, its intuitions about price impact due to adverse selection are robust to the the presence of naïve feedback traders. Indeed, investors who indiscriminately buy (sell) the stock at $t = 1$ after observing a price increase (decrease) at $t = 0$ do not affect our equilibrium price functions to the extent that they do not

[9]Without noise, when $m \neq s$ and with continuous distributions, $\theta_m = \theta_s$ is a zero-probability event, implying that speculators at $t = 1$ know almost surely whether their signal is novel or stale (i.e., uncertainty about what's in the price disappears).

[10]Alternatively, and as noted above, noise in the $t = 0$ price could come from another group of speculators trading with noise traders at $t = 0$.

[11]In our empirical analysis below, we therefore focus on liquidity measures related to adverse selection risk.

change the informativeness of order flow.[12]

Finally, note that our assumption about speculators having mean-variance preferences can be replaced by speculators being risk neutral but facing position limits. In that case, uncertainty about what's in the price again causes price impact to be asymmetric across buys and sells depending on θ_m (as in Proposition 3). The only difference with respect to our current setup is that speculators' trading aggressiveness is no longer asymmetric but dictated by the position limit.

3 How important is uncertainty about what's in the price?

3.1 Testable hypotheses

In this section, we present a first evaluation of the relevance of uncertainty about what's in the price (UWIP). Specifically, we derive from Corollaries 5-7 in Section 2.4 distinct predictions that help assess whether UWIP is an actual concern for stock market participants.

Our first two hypotheses follow from the asymmetry in equilibrium price functions that arises when investors face UWIP (see Corollaries 5 and 6).

Hypothesis 1. *Stock return skewness depends negatively on past returns.*

Hypothesis 2. *Price impact costs depend asymmetrically on past returns: they decrease in past returns for buys and increase in past returns for sells.*

We further hypothesize that, at certain times and for certain stocks, it should be easier for investors to understand what information is already reflected in the price; in those instances, the dependence of return skewness on past returns and the asymmetry

[12]Specifically, if the amount of feedback trading could be perfectly anticipated by market makers, Proposition 4 would remain unchanged except that the order flow would then be centered on this amount of feedback trading (instead of zero). If the amount of feedback trading were uncertain, it would essentially add noise to the order flow without altering the model's key intuitions; namely that speculators learn about the novelty of their signals from past price movements and market makers take this into account by charging a higher price impact for order flow that goes against recent price movements.

for price impact costs should be weaker. For instance, immediately after earnings announcements, investors understand that recent price movements are driven by the public earnings news (i.e., in the language of our model, m is common knowledge), making it easier for them to assess whether their own information is already priced in. We therefore posit that UWIP, and the associated effects of past returns on return skewness and price impact costs, are weaker after earnings announcements. In a similar vein, large stocks and stocks with high analyst coverage have more transparent prices and we thus expect them to exhibit a weaker dependence of return skewness and price impact costs on past returns:

Hypothesis 1'. *The dependence of return skewness on past returns weakens i) after earnings announcements, and ii) for large stocks and stocks with high analyst coverage.*

Hypothesis 2'. *The asymmetric dependence of the price impact of buys and sells on past returns weakens i) after earnings announcements, and ii) for stocks with more transparent prices.*

Our final hypothesis concerns stock price informativeness. As explained above, when risk-averse investors face uncertainty about what's in the price, they trade less aggressively, thereby impounding less information into the price (Corollary 7). Hence, we have the following prediction:

Hypothesis 3. *More uncertainty about what's in the price is associated with less informative stock prices.*

3.2 Data and methodology

Our sample comprises the union of the CRSP and TAQ databases for the 1993-2014 period. Throughout our analyses, we focus on common stocks (share codes 10 or 11) and exclude penny stocks (closing price $< \$1$). With regard to the TAQ data, we apply the filters and adjustments described by Holden and Jacobsen (2014) for dealing with withdrawn or canceled quotes, and we use their interpolated time technique to improve the accuracy of mid-quote prices.

We sign all TAQ trades using the Lee and Ready (1991) algorithm. To obtain signed dollar volumes, we multiply the number of shares traded with the prevailing mid-quote at the end of the 5-minute interval containing the trade. We then sum over all signed dollar volumes to obtain the daily trade imbalance, which captures the net-buy or net-sell activity by liquidity consumers (i.e., market order users) on a given date.

3.2.1 Skewness and price impact measures

We measure a stock's daily return skewness as the realized daily skewness based on intraday returns standardized by the realized variance:

$$\text{skewness}_{it} = \frac{\sqrt{K}\sum_{k=1}^{K}\left(\text{return}_{itk} - \overline{\text{return}}_{it}\right)^3}{\left[\sum_{k=1}^{K}\left(\text{return}_{itk} - \overline{\text{return}}_{it}\right)^2\right]^{3/2}},$$

where return_{itk} is the return (calculated from bid-ask midpoints) over 5-minute interval k for stock i and day t, $\overline{\text{return}}_{it}$ is the return of stock i averaged over all 5-minute intervals comprising day t, and K denotes the number of such intervals on day t. Negative (positive) values indicate that the stock's return distribution has a left tail that is fatter (thinner) than the right tail.

We employ four different price impact measures that are designed to capture adverse selection risk (as faced by the market makers in our model). The first three make use of TAQ data and the last only requires CRSP. Our first measure is a signed version of the Amihud (2002) illiquidity ratio. Specifically, we define the *price impact costs* for stock i on day t as

$$\text{price impact}_{it} = \frac{\text{return}_{it}}{\text{trade imbalance}_{it}},$$

where the return in the numerator is adjusted for the autocorrelation in daily returns.[13] The difference with the Amihud ratio is that we use the signed trade imbalance rather

[13]We find even stronger results if we don't adjust returns for autocorrelation (available upon request). The adjustment for autocorrelation is done as follows: for a daily return of stock i in month $\tau(t)$, we run a regression of stock i's return on lagged returns over the past one to five days, denoted by subscript j, using the previous twelve month ($\tau - 12$ to $\tau - 1$) and record the autocorrelation coefficients $\hat{\beta}_{i\tau(t)j}$. The return adjusted for autocorrelation is defined as $\text{return}_{it} - \sum_{j=1}^{5}\hat{\beta}_{i\tau(t)j} \times \text{return}_{it-j}$.

than trading volume in the denominator, and accordingly also use signed returns in the numerator. This choice is motivated by our model, in which market makers set prices after observing the net order flow (i.e., the trade imbalance). Intuitively, our measure captures by how much the stock price increases (decreases) for one dollar of buying (selling) volume, with higher values indicating higher price impact costs.

Our second adverse selection measure, *lambda*, is the slope coefficient from a regression of stock returns on signed order flow over five-minute intervals; it can be interpreted as the cost of demanding a certain amount of liquidity over five minutes (see Hasbrouck, 2009). The third measure is *quote-based price impact*, defined as the dollar-weighted daily average of the percentage change in the mid-quote from before to five minutes after the transaction. Our last measure, *Ln(Amihud)*, is the standard Amihud (2002) illiquidity ratio, defined as the logarithm of the stock's absolute return divided by its dollar volume.[14] Goyenko et al. (2009) show that it does a good job of capturing adverse selection. We winsorize skewness and price impact measures, as well as other continuous variables used in this study, at the 1% level on both sides.

3.2.2 Methodology

Our model's key predictions are that a stock's daily return skewness depends negatively on past returns (H1) and that price impact costs for buys and sells depend asymmetrically on past returns: they decrease in past returns for buys and increase in past returns for sells (H2). The model is agnostic about the horizon over which past returns should be measured; they may be measured intraday, over one day, or over multiple days. Accordingly, we consider in our empirical tests time windows spanning one, five, and ten trading days (to which we refer as the "lookback window").

Specifically, for skewness, we run the following regression:

$$\text{skewness}_{it} = \alpha_{i\tau} + \alpha_t + \beta\,\text{past return}_{it} + \gamma\,X_{it-1} + \epsilon_{it}\,,$$

[14] Because this ratio can be zero, we add a small constant (0.00000001) before taking logs. The constant is chosen so as to make the Amihud ratio's distribution closer to a normal. Our results are robust to alternative choices for this constant, including dropping it altogether.

where skewness_{it} is the return skewness measured for stock i on trading day t, $\alpha_{i\tau}$ and α_t are stock-month and day fixed effects, past return_{it} is stock i's return over the lookback window (that is, on the prior trading day $(t-1)$, cumulated over the previous five trading days ($t-5$ to $t-1$), or cumulated over the previous ten trading days ($t-10$ to $t-1$)), and X_{it-1} is a vector of controls, which includes past turnover and past squared return (as a proxy for volatility) measured over the same lookback window. Our theory predicts $\beta < 0$.

For price impact, we run the following pair of regressions separately for days with positive and negative net-buying activity:

$$\text{price impact}_{it} = \alpha_{i\tau} + \alpha_t + \beta^b \,\text{past return}_{it} + \gamma\, X_{it-1} + \epsilon_{it} \quad \text{if} \quad \text{trade imbalance}_{it} > 0$$

$$\text{price impact}_{it} = \alpha_{i\tau} + \alpha_t + \beta^s \,\text{past return}_{it} + \gamma\, X_{it-1} + \epsilon_{it} \quad \text{if} \quad \text{trade imbalance}_{it} < 0$$

where price impact_{it} is one of our four price impact proxies. Our theory predicts $\beta^b < 0$ and $\beta^s > 0$. When the past return is simply the stock's prior-day return, our price impact regressions are potentially confounded by the negative autocorrelation of returns (reversals) observed in individual stock return data. Indeed, a negative return yesterday predicts a positive return today, which enters the numerator of the first of our price impact measures. Since the denominator of this measure is by definition positive (negative) in the sample of days with positive (negative) trade imbalance, one may mechanically find $\beta^b < 0$ and $\beta^s > 0$. This is why we used autocorrelation-adjusted returns in the construction of this price impact measure.

Note that, because our models are saturated with stock-month and date fixed effects, we are controlling for stock-specific variations in skewness and illiquidity costs and for any persistent firm characteristics (e.g., analyst coverage and market capitalization). For price impact, for instance, our identification comes from the incremental effect of past returns on price impact costs, separately for buys and sells, while controlling for the average level of price impact costs for the stock in the same month and for the average level of price impact costs across stocks on the same day. In the paper, we carry out our tests with raw returns. In Internet Appendix 1.1, we show that our results are robust to using Fama-French 3-factor alphas.

3.2.3 Descriptive statistics

Table 1 Panel (a) reports summary statistics for our dependent and independent variables in the overall sample. For better visibility, *price impact costs*, *lambda*, and *quote-based price impact* are scaled by 10^6, 10^4, and 10^2, respectively. For instance, the median of the *price impact costs* variable implies that a one million USD net buy would be expected to push up the price by 0.87%. For the *quote-based price impact*, the median is slightly lower at 0.14%. The mean and median of our *return skewness* measure have opposite signs, but are both close to zero. The table also shows the standard deviation for each of our dependent and independent variables, which we use below to assess the economic significance of our findings.

An old literature finds that the price impact for institutional block purchases is larger than the price impact for block sales (Kraus and Stoll, 1972; Keim and Madhavan, 1996; this empirical fact motivates the Saar, 2001, model). Table 1 Panel (b) reports that, for three out of four price impact measures, the price impact is on average slightly higher on days with net-selling activity, as compared to days with net-buying activity. Hence, if anything, the price impact for sells is larger than the price impact for buys in our (more recent) sample.

3.3 Baseline results

Table 2 shows the results of the skewness tests for the different lookback windows. Consistent with hypothesis H1, we find a strong negative relation between return skewness and past returns regardless of whether we focus on lagged 1-day returns (Column 1), lagged 5-days returns (Column 4), or lagged 10-days returns (Column 7). The economic magnitude of the effect is meaningful. For example, a 1-SD increase in lagged 10-days returns decreases daily return skewness by about 12% ($-3.16 \times 0.11/2.90$) of its SD.

Earlier work documents that return skewness is negatively related to lagged returns at *low* frequency (e.g., Harvey and Siddique, 2000; Chen et al., 2001) and attributes this phenomenon to the gradual build-up and eventual burst of stock price bubbles (Chen et al., 2001). Our results show that the skewness-return relationship also exists at *high* frequency—where bubbles are a less plausible explanation—and that it is a distinct phenomenon. Indeed, when we split the sample according to whether the past return is negative or positive (confer Columns 2-3, 5-6, and 8-9), we find that the negative skewness-return relationship is not confined to positive returns as the bubble explanation posits. Instead, we find that this relationship is as (if not more) pronounced after negative returns. While this fact is hard to reconcile with an explanation based on bubbles, it naturally follows from our model.

Table 3 shows the results of the price impact tests. Each panel focuses on one price impact measure. Regardless of whether we look at *price impact costs* (Panel (a)), *lambda* (Panel (b)), *quote-based price impact* (Panel (c)), or *ln(Amihud)* (Panel (d)) and regardless of the lookback window, we consistently obtain results in line with the model's prediction: on days with a positive trade imbalance (net-buys), price impact is significantly negatively related to past returns; whereas on days with a negative trade imbalance (net-sells), price impact is significantly positively related to past returns. The only exception occurs for the *quote-based price impact* at the 1-day lookback window, for which the regression coefficient on the lagged return for net sells is negative (Panel (c), Column 2), but the coefficient estimate and its statistical significance are an order of magnitude smaller than for net buys (Panel (c), Column 1).

Results are highly statistically significant and appear to grow stronger with the length of the lookback window. For instance, a 1-SD increase in the lagged 1-day return decreases (increases) the *price impact costs* on days with a positive (negative) net trade imbalance by about 5% of its SD, thus driving a wedge between the *price impact costs* on buy- and sell-days of about 10% of its SD. The wedge equals about 12% of a SD for the 10-days lookback window. A similar pattern is observable for the *lambda* and the *quote-based price impact* measures, although the magnitudes are weaker. These results indicate that uncertainty about what's in the price is not only a short-term concern for market participants but one that extends over many days.

We emphasize that we control in our regressions for stock-specific trends in liquidity by including stock-month fixed effects.[15] Moreover, our comprehensive panel dataset—covering all NYSE stocks for a 12-year period—yields strong statistical power as indicated by the large t-statistics (despite of double-clustering standard errors by stock and date). In conclusion, the results in Table 3 strongly support hypothesis H2.

3.4 Cross-sectional results

In this subsection, we conduct powerful auxiliary tests of our theory. If, as we argue, the dependence of skewness and price impact on past returns is caused by uncertainty about what's in the price, then it should be less pronounced i) at times when this uncertainty is lower, and ii) for stocks with lower information asymmetry (H1' and H2'). For brevity, we display here results for the 10-days lookback window.[16]

Our first test tracks stocks over time and investigates whether the asymmetric price impact pattern weakens immediately after earnings announcements—when investors know better what information is already reflected in stock prices. To implement this test, we amend our skewness regression as follows:

$$\text{skewness}_{it} = \alpha_{i\tau} + \alpha_t + \beta_1 \, \text{past return}_{it} + \beta_2 \, \text{EA}_{it} + \beta_3 \, \text{past return}_{it} \times \text{EA}_{it} + \gamma \, X_{it-1} + \epsilon_{it} \, ,$$

where EA_{it} is a dummy variable that takes the value of one when stock i on date t had an earnings announcement over the past 10 trading days.[17] Likewise, we modify our

[15] In Internet Appendix 1.1, we further show that our results are robust to using Fama-French 3-factor alphas instead of raw returns.

[16] In Internet Appendix 1.2, we report similar results for the 1-day and the 5-days lookback windows.

[17] We retrieve earnings announcement dates from I/B/E/S. Accordingly, we run this test only for stocks with I/B/E/S data.

price impact regressions as follows:

$$\text{price impact}_{it} = \alpha_{i\tau} + \alpha_t + \beta_1^b \,\text{past return}_{it} + \beta_2^b \,\text{EA}_{it} + \beta_3^b \,\text{past return}_{it} \times \text{EA}_{it} + \gamma\, X_{it-1} + \epsilon_{it}$$
$$\text{if trade imbalance}_{it} > 0$$
$$\text{price impact}_{it} = \alpha_{i\tau} + \alpha_t + \beta_1^s \,\text{past return}_{it} + \beta_2^s \,\text{EA}_{it} + \beta_3^s \,\text{past return}_{it} \times \text{EA}_{it} + \gamma\, X_{it-1} + \epsilon_{it}$$
$$\text{if trade imbalance}_{it} < 0$$

The variable past $\text{return}_{it} \times \text{EA}_{it}$ denotes the interaction of the earnings announcement dummy with the past return. All other variables and fixed effects are as in our baseline regression. Based on our theory, we expect $\beta_1 < 0$, $\beta_1^b < 0$, and $\beta_1^s > 0$, but $\beta_3 > 0$, $\beta_3^b > 0$, and $\beta_3^s < 0$. In words, return skewness should be negatively related to past returns, but this relation should be weakened just after earnings announcements. Likewise, on buy-days (sell-days), price impact should be negatively (positively) related to past returns, but less so just after earnings announcements.

Table 4 Panel (a) presents the results. For return skewness (Column 1), the coefficient estimate on past returns interacted with the earnings announcement dummy (β_3) is significantly positive, indicating that the negative effect of past returns on skewness weakens after earnings announcements. In terms of magnitude, earnings announcements reduce the skewness-return relation by more than one quarter ($0.55/2.03 = 27\%$). Similarly, price impact reacts asymmetrically to past returns on buy- and sell-days, but this asymmetric reaction is strongly muted after earnings announcements. Indeed, β_3 has consistently the opposite sign of β_1 and has a magnitude that, while lower than β_1, remains important. For instance, for *price impact costs* (Columns 2-3), the results indicate that the effect of past returns on price impact is about a third lower ($1.19/3.47 = 34\%$) when an earnings announcement occurred over the previous 10 trading days.[18]

[18]This finding speaks against an alternative explanation whereby the negative relation between return skewness and lagged returns stems from a combination of short sale constraints and disagreement about the precision of public news (Xu, 2007). More specifically, in the Xu (2007) model, short sale-constrained investors disagree on the precision of a publicly observed signal, leading to an overreaction (underreaction) to positive (negative) realizations of that signal. As a consequence, return skewness is positively correlated with contemporaneous returns, but negatively correlated with lagged returns.

Our second set of tests exploits variations across stocks (and over time) in the degree of uncertainty about what's in the price. Specifically, we argue that investors face less such uncertainty about stocks with more public scrutiny; i.e., larger stocks and stocks with more analysts. The idea is that such stocks have a more transparent public information environment, implying that the scope for information asymmetry and thus UWIP is reduced. The tests are similar to the preceding ones, except that we now interact past returns with market capitalization and analyst coverage, instead of an earnings announcement dummy.[19] The findings are reported in Table 4 Panel (b) and Panel (c). They again lend support to our mechanism: the dependence of skewness on past returns and the asymmetry in price impact on buy- and sell-days is reduced for larger stocks and for stocks with more analyst coverage.

Finally, we test whether the dependence of skewness and price impact on past returns is mediated by short sale constraints. We do so as prior explanations for this dependence rely on short sale constraints (e.g., Saar, 2001; Hong and Stein, 2003; Xu, 2007). For instance, in Saar (2001), sells become relatively more informed after positive past returns because the stock is then more likely to be held by informed mutual funds (who bought the stock during the price run-up), implying that the short sale constraint binds less. This leads to an asymmetry in price impact between buys and sells that varies as a function of past returns. Similarly, in Hong and Stein (2003), short sale constraints prevent the views of bearish investors from being incorporated into prices. Their accumulated hidden information comes out during market declines, thus causing negative return skewness. In each case, short sale constraints are at the root of the asymmetry—thus, according to these theories, asymmetries in skewness and price impact should increase (decrease) as short sale constraints tighten (loosen).

To proxy for the tightness of short sale constraints, we use equity lending fees from IHS Markit, the leading provider of such data.[20] The higher the lending fee, the more

Under this explanation, one would have expected the return-skewness relation to be more pronounced in the immediate aftermath of (public) earnings announcements. We find the opposite.

[19] As we measure market capitalization and analyst coverage at the end of the previous month, the level effect of these variables is subsumed by the stock-month fixed effects.

[20] Our equity lending data spans the period from July 2006 to the end of our sample period.

expensive it is to borrow the stock and thus the more constrained is short selling. We then interact the stock's past returns with its average lending fee over the previous month. Table 4 Panel (d) shows the results. We find that short selling costs have no bearing on the dependence of return skewness on past returns (Column 1). This is inconsistent with the Hong and Stein (2003) and Xu (2007) explanations and suggests that—at least at the daily frequency—the observed skewness-return relation is more likely driven by a mechanism that does not rely on short sale constraints such as ours. For price impact (Columns 2-9), we find that short sale constraints do not increase the price impact asymmetry between buys and sells (as the interaction coefficients are negative on both net-buy and net-sell days). In particular, the negative interaction coefficients on net-sell days are inconsistent with the Saar (2001) model, as they imply that short sale constraints weaken, rather than strengthen, the price impact of sells observed after positive returns.[21] This suggest that our results are not driven by short sale constraints.

In summary, the results in this section are in strong agreement with hypotheses H1 and H2, as well as with hypotheses H1' and H2', while being inconsistent with alternative explanations relying on short sale constraints. They thus lend support to the idea that UWIP is a real and important concern for investors.

3.5 Price informativeness

In this section, we test whether UWIP is associated with a lower stock price informativeness as predicted by hypothesis H3. We test this prediction in the context of earnings announcements. Specifically, we measure the price jump around earnings announcement dates, and regress it on a self-constructed, model-implied, proxy for the

[21] We note that our baseline model cannot explain why we find a negative interaction coefficient between short sale constraints and past returns. However, we suspect that an extended model with short sale constraints can deliver this prediction. To see this, consider a version of our model in which the $t = 0$ price reflects the trading by another group of informed investors. If these investors are short sale constrained, $t = 0$ prices will be less informative and so less helpful for assessing the staleness of a signal. Hence, when determining trading aggressiveness and price impact, market participants put less weight on past returns.

extent of uncertainty about what's in the price.

We follow Weller (2018) and construct the price jump ratio as the fraction of earnings-related information that is incorporated into the stock price *prior* to an earnings announcement. The intuition behind this measure follows straight from models of informed trading (e.g., Kyle, 1985; Back, 1992): the price drifts toward the post-announcement asset value ahead of the announcement as investors trade on their private information. Competition among informed traders accelerates this process, resulting in even more information impounded into prices before the announcement (Holden and Subrahmanyam, 1992). As such, the price jump ratio is a direct measure of the information content of stock prices (Weller, 2018). In contrast, widely used measures such as pricing error variance (Hasbrouck, 1993) or variance ratio tests (Lo and MacKinlay, 1988) only measure price efficiency (i.e., whether stock prices follow a random walk and thus accurately reflect available public information) and are therefore not suitable for our purpose.

We construct the price jump ratio as described in Weller (2018). Here, we provide a brief summary of his approach and refer the reader to his paper for more detail. We start from the sample of quarterly earnings announcements over the years 1995 to 2014. We estimate abnormal returns relative to the Fama and French (1992) three-factor model using daily returns over a 365-calendar day window ending 90 days before the earnings announcement. We retain the estimated factor loadings if at least 63 non-missing return observations are available in the estimation window. Abnormal returns around earnings announcements are then cumulated in event-time. Finally, the price jump ratio for stock i and event date t is defined as:

$$\text{jump}_{it} = \frac{CAR_{it}^{(T-1,T+2)}}{CAR_{it}^{(T-21,T+2)}}$$

A high price jump ratio corresponds to a large announcement-date jump relative to the pre-announcement drift and thus indicates a *low* level of price informativeness. As explained by Weller (2018), the price jump ratio is only meaningful for announcements with a sufficiently large information content. We therefore only retain announcement events that satisfy

$$\left|CAR_{it}^{(T-21,T+2)}\right| > \sqrt{24}\hat{\sigma}_{it}$$

where $\hat{\sigma}_{it}$ is the stock's daily return volatility calculated over trading days $T-42$ to $T-22$. In our final sample, the price jump ratio has a mean of 35%, suggesting that, for the average announcement event, a significant fraction of the information enters prices before the announcement date. This figure is in line with what is reported in Weller (2018).

Our measure of uncertainty about what's in the price builds on the key intuition of our model: the more unsure speculators are about what's in the price, the more negative the dependence of return skewness on past returns. To capture this effect, we run for each announcement event the following regression using one year of daily data prior to the earnings announcement for the 10-day lookback window:[22]

$$\text{return skewness}_{i\tau} = \beta_0 + \beta_1 \,\text{past return}_{i\tau} + \epsilon_{i\tau}\,.$$

The coefficient of interest, β_1, captures the the sensitivity of return skewness with respect to past returns. Our model predicts that $\beta_1 < 0$ and hence a lower coefficient estimate indicates more uncertainty about what's in the price. Accordingly, we define $\text{uwip}_{it}^{raw} = -\hat{\beta}_1$. To mitigate the effect of outliers, we winsorize uwip_{it}^{raw} (as well as all other variables used in our regression below) at the 1% level on both sides. For robustness, we define uwip_{it}^{dec} as the decile rank of uwip_{it}^{raw}; i.e., uwip_{it}^{dec} takes on values from one (lowest UWIP) to ten (highest UWIP) depending on the corresponding decile of $\hat{\beta}_1$.

For our price informativeness tests, we regress the price jump ratio on our measure of UWIP:

$$\text{jump}_{it} = \alpha_i + \alpha_t + \beta\,\text{uwip}_{it} + \gamma\, X_{it-1} + \epsilon_{it}$$

[22] In Internet Appendix 1.3, we report consistent results for 1-day and 5-days lookback windows.

where α_i and α_t are stock and date fixed effects, respectively, and X_{it-1} is a vector of pre-determined control variables comprising past turnover, return volatility, market capitalization, and analyst coverage (all control variables are defined in the header of Table 5 below).

Table 5 shows the results for uwip^{raw} (Columns 1-3) and uwip^{dec} (Columns 4-6), respectively. Looking at Column (1), we find a significantly positive effect of uwip^{raw} on the price jump ratio, implying that uncertainty about what's in the price is associated with a lower stock price informativeness as predicted by our model. In terms of economic magnitude, a 1-SD increase (≈ 0.0032) in uwip^{raw} increases the price jump ratio by about 1.2 percentage points, or about 4% relative to its unconditional mean (35%). Adding stock and industry-year fixed effects does not alter this picture: the coefficient estimate for uwip^{raw} barely changes and remains highly statistically significant. Columns 4-6 show that these findings are robust to using decile ranks instead of the raw measure, implying that the results are not driven by outliers. Here, the magnitude implies that moving from the 1st to the 10th decile of uwip^{raw} increases the price jump ratio by about 4% percentage points, or about 11% relative to its unconditional sample mean. Overall, these results confirm hypothesis H3: uncertainty about what's in the price slows down the incorporation of fundamental information into prices and hurts stock price informativeness.

4 Conclusion

This paper proposes a simple model in which speculators are unsure whether their signals are stale (i.e., already priced in) or novel—and thus valuable to trade on. In equilibrium, speculators assess the novelty of their signal by comparing it to the most recent price movement and adjust their trading aggressiveness accordingly. Market makers, in turn, anticipate that speculators may be trading on stale news. The resulting price function is asymmetric: after price increases (decreases), market makers consider incoming buy volume to be less (more) informative and thus charge a lower (higher) price impact compared to sell volume. As a results, return skewness is negatively related to past price changes. Moreover, by making speculators reluctant to trade, uncertainty about what's in the price decreases stock price informativeness.

Using daily order flow data for a comprehensive panel of NYSE-traded stocks, we find strong support for these predictions. Specifically, we document that (1) return skewness is negatively associated with past returns and that (2) on days with a positive (negative) trade imbalance, price impact costs are negatively (positively) related to past stock returns. Moreover, we find that these dependencies are reduced after earnings announcements and for stocks with a large market capitalization and a high analyst coverage; i.e., when speculators know better whether their private signals are novel or stale. Overall, our results strongly suggest that uncertainty about what's in the price is a common and widespread concern for stock market participants.

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Figure 1: Model setup

This figure summarizes the model setup. At $t = 0$, market makers M observe θ_m, where $m \in \{1, 2\}$ with equal probability, and set $p_0 = \theta_m$. At $t = 1$, speculators S observe θ_s, where $s \in \{1, 2\}$ with equal probability, and submit market order to maximize expected utility. Market makers observe the net order flow, consisting of the sum of speculators' market orders and noise trades, and set $p_1 = E(\theta|\theta_m, \omega)$. At $t = 2$, the stock's payoff $\theta = \theta_1 + \theta_2$ is realized and consumption takes place.

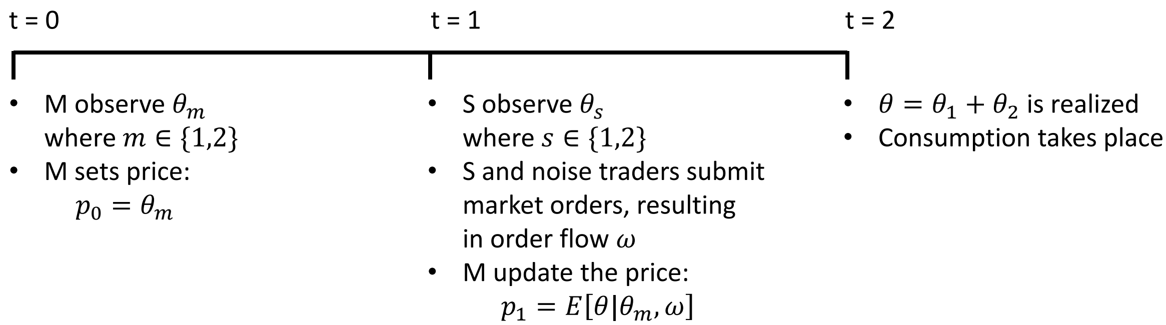
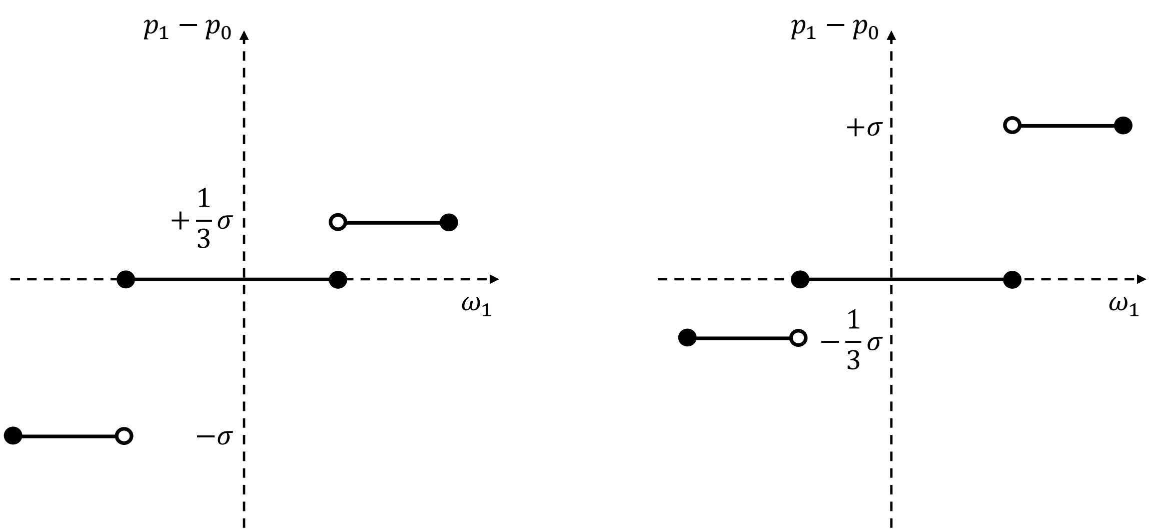


Figure 2: Equilibrium price function

This figure shows the equilibrium price function when speculators face uncertainty about whether their trading signal is already in the price. In Panel A, we show the price function for the case of prior positive news ($\theta_m = +\sigma$). In Panel B, we show the price function for prior negative news ($\theta_m = -\sigma$).



Panel A: For $\theta_m = +\sigma$

Panel B: For $\theta_m = -\sigma$

Table 1: **Descriptive statistics**

This table reports descriptive statistics. Panel (a) shows statistics for our dependent and independent variables in the overall (stock-day) sample. Panels (b) and (c) show descriptive statistics separately for days with positive net trade imbalance (*net-buy* subsample) and negative net trade imbalance (*net-sell* subsample). *Return skewness* is defined as realized skewness standardized by realized variance of 5-min relative price changes on a given day. *Price impact costs* is defined as the ratio of the (autocorrelation-adjusted) return over the net trade imbalance. The measure is multiplied by 10^6 for better visibility. *Lambda* is defined as the slope coefficient of regressing stock returns on signed order flow over five-minute intervals. The measure is multiplied by 10^4 for better visibility. *Quote-based price impact* is defined as the dollar-weighted average of the percentage change in the mid-quote from right before the transaction to five minutes after the transaction. The measure is multiplied by 10^2 for better visibility. *Ln(Amihud)* is the Amihud (2002) illiquidity ratio, defined as the logarithm of (a small constant plus) the ratio of absolute return over dollar volume. Past X-day return is the cumulated raw return over the previous X trading days. Past X-day turnover is the average share turnover over the previous X trading days. Past X-day volatility is the average of squared raw return over the previous X trading days. All dependent and independent variables are winsorized at the 1% level on both sides.

Panel (a): Descriptive statistics for overall sample

	Mean	Median	Standard deviation
Dependent variables			
Return skewness	-0.0152	0.0309	2.8967
Price impact costs	0.6063	0.0087	5.8523
Lamdba	0.1413	0.0224	0.4777
Quote-based price impact	0.3966	0.1443	0.7834
Ln(Amihud)	-16.9706	-17.8151	1.8021
Independent variables			
Past 1-day return	0.0008	0.0000	0.0348
Past 5-days return	0.0045	0.0016	0.0752
Past 10-days return	0.0090	0.0051	0.1055
Past 1-day turnover	0.0068	0.0036	0.0095
Past 5-days turnover	0.0070	0.0040	0.0087
Past 10-days turnover	0.0070	0.0042	0.0084
Past 1-day volatility	0.0013	0.0002	0.0035
Past 5-days volatility	0.0015	0.0005	0.0029
Past 10-days volatility	0.0015	0.0006	0.0027
N	22,433,401		

Panel (b): Descriptive statistics for *net buy*-days

	Mean	Median	Standard deviation
Return skewness	0.4701	0.2214	2.6946
Price impact costs	0.5580	0.0045	5.8843
Lamdba	0.1281	0.0196	0.4549
Quote-based price impact	0.3762	0.1380	0.7472
Ln(Amihud)	-17.1107	-17.9662	1.7354
N	11,061,604		

Panel (c): Descriptive statistics for *net sell*-days

	Mean	Median	Standard deviation
Return skewness	-0.4872	-0.1883	3.0063
Price impact costs	0.6534	0.0157	5.8208
Lamdba	0.1541	0.0259	0.4986
Quote-based price impact	0.4165	0.1514	0.8166
Ln(Amihud)	-16.8343	-17.6305	1.8545
N	11,371,797		

Table 2: **Return skewness and past returns**

This table reports the results from regressing daily *return skewness* on lagged raw returns as explained in Section 3.2. Columns (1)-(3) show the results for using lagged 1-day returns as the key independent variable. Columns (4)-(6) show the results for using lagged cumulated 5-day returns as the key independent variable. Columns (7)-(9) show the results for using lagged cumulated 10-day returns as the key independent variable. The past turnover and past volatility controls are chosen accordingly. Columns (1), (4), and (7) show results for the overall sample; Columns (2), (3), (5), (6), (8), and (9) break up the sample into days with a negative or positive past return, respectively. All regressions contain stock-month and date fixed effects. t-statistics are based on standard errors adjusted for double-clustering by stock and day. ***, ** and * indicate statistical significance at the 1%, 5% and 10% level, respectively.

	Lagged 1-day			Lagged 5-days			Lagged 10-days		
	All days	≤ 0	> 0	All days	≤ 0	> 0	All days	≤ 0	> 0
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Past return	-0.8531***	-1.4637***	0.6213***	-2.0598***	-4.1087***	-3.1597***	-2.3196***	-3.9835***	-3.4973***
	(-24.61)	(-15.19)	(6.34)	(-74.27)	(-71.29)	(-71.72)	(-74.27)	(-77.09)	(-79.71)
Past turnover	-0.2307	1.8332***	-3.8769***	-2.2566***	-3.0702***	-3.2762***	-2.9110***	-4.5620***	-2.0980***
	(-1.63)	(9.92)	(-21.71)	(-10.83)	(-10.14)	(-11.16)	(-10.36)	(-10.39)	(-5.47)
Past volatility	12.5636***	18.2397***	-2.5886***	20.4112***	6.3265***	30.1649***	31.3325***	4.5639***	52.5382***
	(34.66)	(24.08)	(-3.96)	(32.94)	(6.72)	(36.53)	(36.02)	(3.34)	(42.48)
Stock-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	23,925,441	13,011,833	10,862,693	23,916,920	11,255,620	12,586,601	23,900,236	10,962,216	12,812,359
adj. R^2	0.06	0.06	0.08	0.06	0.08	0.08	0.07	0.08	0.08

Table 3: **Price impact and past returns**

This table reports the results from regressing our four price impact measures on lagged raw returns as explained in Section 3.2. Panel (a) shows the results for the *price impact costs* measure (scaled by 10^6 for better visibility). Panel (b) shows results for the *lambda* measure (scaled by 10^4 for better visibility). Panel (c) shows results for the *quote-based price impact* measure (scaled by 10^2 for better visibility). Panel (d) shows results for the *ln(Amihud)* measure. In each panel, Columns (1)-(2) show results for using lagged 1-day returns as the key independent variable, Columns (3)-(4) show results for using lagged cumulated 5-day returns as the key independent variable, and Columns (5)-(6) show results for using lagged cumulated 10-day returns as the key independent variable. The past turnover and past volatility controls are chosen accordingly. Odd columns show results for the net-buy subsample (i.e., all stock-day observations on which the trade imbalance is positive). Even columns show results for the net-sell subsample (i.e., all stock-day observations on which the trade imbalance is negative). All regressions contain stock-month and date fixed effects. t-statistics are based on standard errors adjusted for double-clustering by stock and day. ***, ** and * indicate statistical significance at the 1%, 5% and 10% level, respectively.

Panel (a): Dependent variable: Price impact costs

	Lagged 1-day		Lagged 5-days		Lagged 10-days	
	Net buys	Net sells	Net buys	Net sells	Net buys	Net sells
	(1)	(2)	(3)	(4)	(5)	(6)
Past return	-9.4514***	8.5174***	-5.1369***	4.2856***	-5.0723***	4.3000***
	(-65.58)	(61.56)	(-66.48)	(62.05)	(-67.89)	(64.56)
Past turnover	-3.7373***	-7.0656***	-3.2730***	2.6141***	2.8449***	7.7188***
	(-10.60)	(-18.72)	(-5.98)	(4.51)	(3.74)	(10.18)
Past volatility	53.2757***	-56.1444***	44.6280***	-103.1488***	26.3797***	-136.6617***
	(36.40)	(-39.18)	(19.67)	(-42.64)	(8.78)	(-43.73)
Stock-month FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
N	11,431,216	11,938,773	11,431,226	11,938,784	11,429,575	11,936,848
adj. R^2	0.14	0.13	0.14	0.13	0.14	0.13

Panel (b): Dependent variable: Lambda

	Lagged 1-day		Lagged 5-days		Lagged 10-days	
	Net buys	Net sells	Net buys	Net sells	Net buys	Net sells
	(1)	(2)	(3)	(4)	(5)	(6)
Past return	-0.1786***	0.0341***	-0.1653***	0.0488***	-0.1558***	0.0538***
	(-27.51)	(5.71)	(-45.40)	(15.71)	(-51.03)	(19.74)
Past turnover	-0.6514***	-0.7526***	-0.6851***	-0.9693***	-0.2931***	-0.7148***
	(-33.33)	(-35.87)	(-21.08)	(-26.89)	(-6.85)	(-15.15)
Past volatility	2.0885***	1.6967***	1.6502***	1.2190***	-0.0559	-1.0658***
	(26.74)	(22.96)	(12.75)	(9.30)	(-0.31)	(-6.15)
Stock-month FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
N	11,825,847	12,416,231	11,822,356	12,411,502	11,815,262	12,401,608
adj. R^2	0.34	0.30	0.34	0.30	0.34	0.30

Panel (c): Dependent variable: Quote-based price impact

	Lagged 1-day		Lagged 5-days		Lagged 10-days	
	Net buys	Net sells	Net buys	Net sells	Net buys	Net sells
	(1)	(2)	(3)	(4)	(5)	(6)
Past return	-0.2384***	-0.0287***	-0.2718***	0.0798***	-0.2751***	0.1110***
	(-23.90)	(-2.99)	(-50.06)	(15.64)	(-59.84)	(24.35)
Past turnover	-1.3397***	-1.2029***	-1.9287***	-1.9634***	-1.7847***	-1.9817***
	(-36.85)	(-32.09)	(-32.92)	(-32.37)	(-22.70)	(-23.92)
Past volatility	4.9203***	5.0447***	3.2237***	3.5559***	-0.3404	-1.2013***
	(38.44)	(39.67)	(15.03)	(16.83)	(-1.13)	(-3.99)
Stock-month FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
N	11,813,957	12,381,069	11,810,491	12,376,357	11,803,398	12,366,497
adj. R^2	0.35	0.30	0.35	0.30	0.36	0.30

Panel (d): Ln(Amihud)

	Lagged 1-day		Lagged 5-days		Lagged 10-days	
	Net buys	Net sells	Net buys	Net sells	Net buys	Net sells
	(1)	(2)	(3)	(4)	(5)	(6)
Past return	-2.2441^{***}	1.9357^{***}	-1.2138^{***}	0.5797^{***}	-1.0008^{***}	0.3774^{***}
	(-87.31)	(65.06)	(-95.20)	(45.87)	(-97.17)	(35.69)
Past turnover	-7.4402^{***}	-9.9764^{***}	-6.5425^{***}	-8.4917^{***}	-3.6437^{***}	-5.2230^{***}
	(-72.50)	(-86.12)	(-46.84)	(-51.81)	(-20.11)	(-24.07)
Past volatility	1.3818^{***}	-4.4124^{***}	-10.0448^{***}	-17.6473^{***}	-21.4307^{***}	-31.8064^{***}
	(6.60)	(-17.93)	(-27.50)	(-41.50)	(-40.19)	(-50.35)
Stock-month FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
N	11,863,191	12,458,894	11,859,687	12,454,140	11,852,537	12,444,181
adj. R^2	0.69	0.63	0.69	0.63	0.69	0.63

Table 4: **Cross-sectional tests**

This table reports results of cross-sectional tests for our return skewness and price impact regressions (see Section 3.2). For brevity, we only show results using lagged cumulated 10-day returns as the key independent variable. Panel (a) shows results for interacting the past return with an *EA* dummy, which flags whether or not there was an earnings announcement for the stock over the previous 10 trading days. The *EA* dummy is also added separately to the regression. Panel (b) shows results for interacting the past return with *Ln(mcap)*, defined as the natural logarithm of the stock's market capitalization at the end of the prior month. *Ln(mcap)* is not added separately to the regression as it is subsumed by the stock-month fixed effect. Panel (c) shows results for interacting the past return with *AnalCov*, defined as the natural logarithm of one plus the number of analysts following the stock at the end of the prior month. *AnalCov* is not added separately to the regression as it is subsumed by the stock-month fixed effect. Panel (d) shows results for interacting the past return with *ShortFee*, defined as the average short selling fee (i.e., equity lending fee) for the stock over the prior month (data comes from Markit and is only available to us for the period from July 2006 onward). *ShortFee* is not added separately to the regression as it is subsumed by the stock-month fixed effect. In each panel, Column (1) shows results for *return skewness* as the dependent variable (using the overall sample), Columns (2)-(3) show results for *price impact costs* as the dependent variable, Columns (4)-(5) show results for *lambda* as the dependent variable, Columns (6)-(7) show results for *quote-based price impact* as the dependent variable, and Columns (8)-(9) show results for *ln(Amihud)* as the dependent variable. Columns (2), (4), (6), and (8) show results for the net-buy subsample (i.e., all stock-day observations on which the trade imbalance is positive). Columns (3), (5), (7), and (9) show results for the net-sell subsample (i.e., all stock-day observations on which the trade imbalance is negative). All regressions contain past turnover and past volatility controls, stock-month and date fixed effects. t-statistics are based on standard errors adjusted for double-clustering by stock and day. ***, ** and * indicate statistical significance at the 1%, 5% and 10% level, respectively.

Panel (a): Interaction with EA

	Return	Price impact costs		Lambda		Quote-based price impact		Ln(Amihud)	
	skewness	Net buys	Net sells	Net buys	Net sells	Net buys	Net sells	Net buys	Net sells
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Past return	-2.0291***	-3.4684***	3.2038***	-0.0982***	0.0269***	-0.2130***	0.0750***	-0.8242***	0.2749***
	(-66.88)	(-58.12)	(57.47)	(-40.00)	(11.64)	(-50.56)	(17.15)	(-84.92)	(27.50)
EA	-0.0296***	-0.0353***	0.0360***	-0.0019***	-0.0011***	-0.0006	0.0007	-0.0225***	-0.0178***
	(-11.07)	(-6.41)	(6.52)	(-6.40)	(-3.30)	(-1.06)	(1.04)	(-20.39)	(-13.23)
Past return*EA	0.5476***	1.1867***	-1.1060***	0.0310***	-0.0113***	0.0462***	-0.0293***	0.2292***	-0.1372***
	(21.54)	(20.76)	(-20.42)	(9.98)	(-3.52)	(7.93)	(-4.62)	(22.15)	(-12.40)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Stock-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	19,386,514	9,609,903	9,605,571	9,870,541	9,904,130	9,864,471	9,882,757	9,898,616	9,935,289
adj. R^2	0.06	0.11	0.07	0.32	0.28	0.34	0.28	0.69	0.64

Panel (b): Interaction with Ln(mcap)

	Return	Price impact costs		Lambda		Quote-based price impact		Ln(Amihud)	
	skewness	Net buys	Net sells	Net buys	Net sells	Net buys	Net sells	Net buys	Net sells
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Past return	-6.9808***	-31.8726***	21.4356***	-1.0862***	0.2850***	-1.3725***	0.4528***	-4.9158***	1.8955***
	(-52.69)	(-64.74)	(46.71)	(-47.71)	(12.39)	(-43.31)	(13.64)	(-92.65)	(29.83)
Past return*Ln(mcap)	0.3926***	2.2276***	-1.4675***	0.0773***	-0.0197***	0.0911***	-0.0292***	0.3252***	-0.1297***
	(40.05)	(58.43)	(-41.03)	(44.83)	(-11.05)	(38.22)	(-11.41)	(81.30)	(-26.96)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Stock-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	23,814,464	11,409,248	11,914,847	11,770,296	12,346,479	11,758,557	12,311,753	11,806,669	12,387,882
adj. R^2	0.07	0.15	0.13	0.34	0.30	0.36	0.30	0.69	0.63

Panel (c): Interaction with AnalCov

	Return	Price impact costs		Lambda		Quote-based price impact		Ln(Amihud)	
	skewness	Net buys	Net sells	Net buys	Net sells	Net buys	Net sells	Net buys	Net sells
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Past return	-3.1621***	-9.7783***	6.9033***	-0.3266***	0.0844***	-0.4853***	0.1628***	-1.7576***	0.5946***
	(-74.15)	(-76.66)	(61.97)	(-54.03)	(15.54)	(-55.75)	(19.69)	(-115.70)	(34.31)
Past return*AnalCov	0.6929***	3.5968***	-2.2730***	0.1319***	-0.0269***	0.1622***	-0.0455***	0.5853***	-0.1914***
	(41.69)	(60.85)	(-42.84)	(46.84)	(-9.85)	(40.35)	(-11.28)	(85.41)	(-24.79)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Stock-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	23,900,236	11,429,575	11,936,848	11,815,262	12,401,608	11,803,398	12,366,497	11,852,537	12,444,181
adj. R^2	0.07	0.15	0.13	0.34	0.30	0.36	0.30	0.69	0.63

Panel (d): Interaction with ShortFee

	Return	Price impact costs		Lambda		Quote-based price impact		Ln(Amihud)	
	skewness	Net buys	Net sells	Net buys	Net sells	Net buys	Net sells	Net buys	Net sells
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Past return	-0.9709***	-4.0388***	3.9532***	-0.0585***	0.0280***	-0.1214***	0.0268***	-0.6215***	0.1044***
	(-37.22)	(-34.55)	(33.57)	(-14.10)	(7.05)	(-17.72)	(4.09)	(-43.08)	(7.49)
Past return*ShortFee	-0.0050	-0.0891***	-0.0286**	-0.0025***	-0.0012*	-0.0032**	-0.0005	-0.0229***	-0.0127***
	(-1.54)	(-4.51)	(-2.16)	(-3.46)	(-1.83)	(-2.46)	(-0.46)	(-10.00)	(-6.37)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Stock-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	7,833,642	3,638,539	3,889,555	3,737,458	3,993,718	3,735,782	3,992,147	3,735,433	3,991,690
adj. R^2	0.08	0.09	0.07	0.16	0.15	0.30	0.28	0.78	0.77

Table 5: **UWIP and Price Informativeness**

This table reports results from regressing the price jump ratio as constructed in Weller (2018) (see Section 3.5 for details) on our measure of uncertainty about what's in the price (*UWIP*) and controls. To construct *UWIP*, we run a regression of return skewness on lagged cumulated 10-day returns over the 252 trading days preceding the earnings announcement. Our model with uncertainty about what's in the price predicts a negative regression coefficient (compare also Table 2); we therefore define *UWIP(raw)* to be the (winsorized) estimated regression coefficient times minus one. *UWIP(dec)* is defined as the decile rank of *UWIP(raw)*. *Ln(turnover)* is the average share turnover over the 252 trading days preceding the earnings announcement. *Return volatility* is the standard deviation of raw returns over the 252 trading days preceding the earnings announcement. *Ln(mcap)* is the (natural logarithm of the) market capitalization at the beginning of the announcement quarter. *Anal coverage* is the (natural logarithm of one plus) the number of analysts following the stock at the beginning of the announcement quarter. Columns (1)-(3) show results using *UWIP(raw)* as the key independent variable (with regression coefficients multiplied by $1,000$ for better visibility). Columns (4)-(6) show results using *UWIP(dec)* as the key independent variable. All regressions contain day fixed effects; Columns (1) and (4) contain industry fixed effects (based on the SIC-2 digit industry classification); Columns (2), (3), (5), and (6) contain stock fixed effects, Columns (5) and (6) further include industry-year fixed effects. t-statistics are based on standard errors adjusted for double-clustering by stock and day. ***, ** and * indicate statistical significance at the 1%, 5% and 10% level, respectively.

	Price jump ratio					
	(1)	(2)	(3)	(4)	(5)	(6)
UWIP(raw)	3.8859***	3.7381***	3.7734***			
	(9.01)	(7.50)	(7.52)			
UWIP(dec)				0.0040***	0.0042***	0.0042***
				(8.61)	(8.39)	(8.28)
Ln(turnover)	0.0040**	-0.0044**	-0.0055**	0.0040**	-0.0044**	-0.0054**
	(2.50)	(-2.00)	(-2.41)	(2.56)	(-1.98)	(-2.38)
Return volatility	-0.9124***	-0.2296**	-0.0856	-0.9041***	-0.2190*	-0.0769
	(-9.44)	(-2.01)	(-0.73)	(-9.36)	(-1.92)	(-0.66)
Ln(mktcap)	0.0002	0.0027	0.0061**	0.0002	0.0026	0.0059**
	(0.17)	(1.10)	(2.35)	(0.14)	(1.03)	(2.30)
AnalCov	0.0242***	0.0256***	0.0268***	0.0245***	0.0258***	0.0270***
	(9.26)	(7.16)	(7.39)	(9.36)	(7.23)	(7.45)
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	No	No	Yes	No	No
Stock FE	No	Yes	Yes	No	Yes	Yes
Industry*year FE	No	No	Yes	No	No	Yes
N	114,555	113,411	113,351	114,555	113,411	113,351
adj. R^2	0.06	0.09	0.09	0.06	0.09	0.09

A Appendix - Proofs

A.1 Proof of Proposition 2 - Both m and s are common knowledge

The main steps of the proof are in the text. Here, we display the calculations for the order size $x_{(1)}$ when $m \neq s$ (if $m = s$, then S do not trade). In that case, the price conjecture in Equation (1) leads to the following:

- If $m \neq s$ and $\theta_s = \sigma$ (which occurs with probability $1/2 \times 1/2 = 1/4$), then S buy $x_{(1)}$ shares so $\omega_1 = x_{(1)} + n$ and

$$\theta - p_1 = (\theta_m + \sigma) - p_1 = \begin{cases} 0 & \text{with proba. } x_{(1)}/4 \text{ (i.e., for } -2x_{(1)} + 1 < n \leq 1) \\ \sigma & \text{with proba. } (1 - x_{(1)})/4 \text{ (i.e., for } -1 \leq n \leq -2x_{(1)} + 1) \\ 2\sigma & \text{with proba. } 0 \text{ (i.e., for } -2x_{(1)} - 1 \leq n < -1) \end{cases}$$

  As a result, $E[\theta - p_1 | p_0, \theta_s = \sigma, m \neq s] = \sigma(1 - x_{(1)})$ and $Var[\theta - p_1 | p_0, \theta_s = \sigma, m \neq s] = \sigma^2 x_{(1)}(1 - x_{(1)})$. Plugging these expressions into the first-order condition for S' profit maximization and imposing rational expectations ($x_i = x_{(1)}$ for all i) yields:

$$x_{(1)} = \frac{E[\theta - p_1 | p_0, \theta_s = \sigma, m \neq s]}{\gamma Var[\theta - p_1 | p_0, \theta_s = \sigma, m \neq s]} = \frac{\sigma(1 - x_{(1)})}{\gamma \sigma^2 x_{(1)}(1 - x_{(1)})}$$

  and hence $x_{(1)} = \sqrt{1/(\gamma\sigma)}$.

- If $m \neq s$ and $\theta_s = -\sigma$ (which occurs with probability $1/2 \times 1/2 = 1/4$), then S sell $x_{(1)}$ shares so $\omega_1 = -x_{(1)} + n$ and

$$\theta - p_1 = (\theta_m - \sigma) - p_1 = \begin{cases} -2\sigma & \text{with proba. } 0 \text{ (i.e., for } 1 < n \leq 2x_{(1)} + 1) \\ -\sigma & \text{with proba. } (1 - x_{(1)})/4 \text{ (i.e., for} 2x_{(1)} - 1 \leq n \leq +1) \\ 0 & \text{with proba. } x_{(1)}/4 \text{ (i.e., for } -1 \leq n < 2x_{(1)} - 1) \end{cases}$$

  Hence, $E[\theta - p_1 | p_0, \theta_s = -\sigma, m \neq s] = -\sigma(1 - x_{(1)})$ and $Var[\theta - p_1 | p_0, \theta_s = -\sigma, m \neq s] = \sigma^2 x_{(1)}(1 - x_{(1)})$. Plugging these expressions into the first-order condition and imposing rational expectations ($x_i = x_{(1)}$ for all i) yields:

$$-x_{(1)} = \frac{E[\theta - p_1 | p_0, \theta_s = -\sigma, m \neq s]}{\gamma Var[\theta - p_1 | p_0, \theta_s = -\sigma, m \neq s]} = \frac{-\sigma(1 - x_{(1)})}{\gamma \sigma^2 x_{(1)}(1 - x_{(1)})},$$

  which yields again $x_{(1)} = \sqrt{1/(\gamma\sigma)}$. Thus, the order size is identical for $\theta_s = +\sigma$ and$\theta_s = -\sigma$, which confirms our conjecture.

A.2 Proof of Proposition 3 - Only m is common knowledge

The main steps of proof are in the text. Here, we first display the calculations for Ms' expectation of θ_s conditional on observing an order flow $-x_{(2)} + 1 \leq \omega_1 \leq 1$ (for other values of the order flow, M either learn θ_s perfectly or nothing at all); in that case, M know that either $m = s$ (and S do not trade) or $m \neq s$ and $\theta_s = \sigma$ (and S buy $x_{(2)}$). The former occurs with a probability 1/2 and the latter with a probability $1/2 \times 1/2 = 1/4$. Hence, $E(\theta_s | -x_{(2)} + 1 \leq \omega_1 \leq 1) = \frac{1/2 \times 0 + 1/4\sigma}{1/2 + 1/4} = \frac{1}{3}\sigma$.
Next, we display the calculations for the order size $x_{(2)}$ when $m \neq s$ (if $m = s$, then S do not trade). In that case, the price conjecture in Equation (2) leads to the following:

- If $m \neq s$ and $\theta_s = \sigma$ (which occurs with probability $1/2 \times 1/2 = 1/4$), then $\omega_1 = x_{(2)} + n$ and

$$\theta - p_1 = (\theta_m + \sigma) - p_1 = \begin{cases} 0 & \text{with proba. } x_{(2)}/8 \text{ (i.e., for } 1 - x_{(2)} < n \leq 1) \\ \frac{2}{3}\sigma & \text{with proba. } x_{(2)}/8 \text{ (i.e., for } -2x_{(2)} + 1 < n \leq 1 - x_{(2)}) \\ \sigma & \text{with proba. } (1 - x_{(2)})/4 \text{ (i.e., for } -1 \leq n \leq -2x_{(2)} + 1) \\ \frac{4}{3}\sigma & \text{with proba. } 0 \text{ (i.e., for } -1 - x_{(2)} \leq n < -1) \\ 2\sigma & \text{with proba. } 0 \text{ (i.e., for } -2x_{(2)} - 1 \leq n < -x_{(2)} - 1) \end{cases}$$

As a result, $E[\theta - p_1 | p_0, \theta_s = \sigma, m \neq s] = \sigma\left(1 - \frac{2}{3}x_{(2)}\right)$ and $Var[\theta - p_1 | p_0, \theta_s = \sigma, m \neq s] = \frac{1}{9}\sigma^2 x_{(2)}(5 - 4x_{(2)})$. Plugging these expressions into the first-order condition for S' profit maximization and imposing rational expectations ($x_i = x_{(1)}$ for all i) yields:

$$x_{(2)} = \frac{E[\theta - p_1 | p_0, \theta_s = \sigma, m \neq s]}{\gamma Var[\theta - p_1 | p_0, \theta_s = \sigma, m \neq s]} = \frac{\sigma\left(1 - \frac{2}{3}x_{(2)}\right)}{\gamma \frac{1}{9}\sigma^2 x_{(2)}(5 - 4x_{(2)})}.$$

Rearranging leads to the cubic equation:

$$9 - 6x_{(2)} - 5\gamma\sigma x_{(2)}^2 + 4\gamma\sigma x_{(2)}^3 = 0 \tag{5}$$

- If $m \neq s$ and $\theta_s = -\sigma$ (which occurs with probability $1/2 \times 1/2 = 1/4$), then $\omega_1 = -x_{(2)} + n$ and

$$\theta - p_1 = (\theta_m - \sigma) - p_1 = \begin{cases} -2\sigma & \text{with proba. } 0 \text{ (i.e., for } 1 + x_{(2)} < n \leq 1) \\ -\frac{4}{3}\sigma & \text{with proba. } 0 \text{ (i.e., for } 1 < n \leq x_{(2)} + 1) \\ -\sigma & \text{with proba. } (1 - x_{(2)})/4 \text{ (i.e., for } 2x_{(2)} - 1 \leq n \leq 1) \\ -\frac{2}{3}\sigma & \text{with proba. } x_{(2)}/8 \text{ (i.e., for } -1 + x_{(2)} \leq n < 2x_{(2)} - 1) \\ 0 & \text{with proba. } x_{(2)}/8 \text{ (i.e., for } -1 \leq n < x_{(2)} - 1) \end{cases}$$

Hence, $E[\theta - p_1 | p_0, \theta_s = -\sigma, m \neq s] = -\sigma\left(1 - \frac{2}{3}x_{(2)}\right)$ and $Var[\theta - p_1 | p_0, \theta_s = -\sigma, m \neq s] = \frac{1}{9}\sigma^2 x_{(2)}(5 - 4x_{(2)})$. Plugging these expressions into the first-order condition yields:

$$-x_{(2)} = \frac{E[\theta - p_1 | p_0, \theta_s = -\sigma, m \neq s]}{\gamma Var[\theta - p_1 | p_0, \theta_s = -\sigma, m \neq s]} = \frac{-\sigma\left(1 - \frac{2}{3}x_{(2)}\right)}{\gamma \frac{1}{9}\sigma^2 x_{(2)}(5 - 4x_{(2)})},$$

which again leads to Equation 5. Therefore, the order size is identical for $\theta_s = +\sigma$ and $\theta_s = -\sigma$, which confirms our conjecture.

To prove the existence and unicity of $x_{(2)}$, let $f(x) \equiv 9 - 6x - 5\gamma\sigma x^2 + 4\gamma\sigma x^3$. Given that $f(0) = 9 > 0$ and $f(1) = 3 - \gamma\sigma < 0$ by Assumption 1, f admits at least one root over the interval [0,1]. Note that, if Assumption 1 does not hold, i.e., if $\gamma\sigma < 3$, then f admits no root over that interval, implying that there is no equilibrium in which speculators' trades are not fully revealing. To establish the unicity of x, differentiate f and observe that $f'(x) = -6 - 10\gamma\sigma x + 12\gamma\sigma x^2$ admits 2 roots, $x_{-/+} = (5\gamma\sigma \pm \sqrt{25\gamma^2\sigma^2 + 72\gamma\sigma})/12$ where $x_- < 0$ and $x_+ > 1$ given Assumption 1. As a result, f' is negative over the interval [0,1], implying that f is monotonically decreasing over that interval. We conclude that f admits at most one root, $x_{(2)}$, over [0,1].

A.3 Proof of Proposition 4 - Neither m nor s are common knowledge

Recall that we conjecture that S buy (sell) an amount $x_{(3)}$ ($-x_{(3)}$) when $\theta_m \neq \theta_s$ and that they buy (sell) an amount $y_{(3)}$ ($-y_{(3)}$) when $\theta_m = \theta_s$ with $x_{(3)} \geq y_{(3)}$. We label $\neg m$ the component of the

fundamental that is not observed by M; for instance, if $m = 1$ (i.e., M observe $\theta_m = \theta_1$), then $\neg m = 2$ (i.e., M do not observe $\theta_{\neg m} = \theta_2$).
The main steps of the proof are in the text. We first display the calculations for Ms' expectation of $\theta_{\neg m}$. Suppose M observe $\theta_m = \sigma$ and an order flow $-x_{(3)} + 1 \leq \omega_1 \leq y_{(3)} + 1$. In that case, M infer that S bought $y_{(3)}$ and hence that $\theta_s = \sigma$. The configuration $\theta_m = \theta_s = \sigma$ occurs either if $m = s$ (probability $1/2 \times 1/2 = 1/4$) or if $m \neq s$ and $\theta_m = \theta_s = \sigma$ (probability $1/2 \times 1/2 \times 1/2 = 1/8$). Hence, $E(\theta_{\neg m}|\theta_m = \sigma, -x_{(3)}+1 \leq \omega_1 \leq y_{(3)}+1) = \frac{1/4\times 0+1/8\sigma}{1/4+1/8} = \frac{1}{3}\sigma$. Suppose M observe $\theta_m = \sigma$ and an order flow $-x_{(3)} - 1 \leq \omega_1 \leq y_{(3)} - 1$. In that case, M infer that S sold $x_{(3)}$ and hence that $\theta_s = -\sigma$. This tells them that $m \neq s$ and therefore that $E(\theta_{\neg m}|\theta_m = \sigma, -x_{(3)} - 1 \leq \omega_1 \leq y_{(3)} - 1) = -\sigma$. Finally, suppose M observes an order flow $y_{(3)} - 1 \leq \omega_1 \leq 1 - x_{(3)}$. Then M learn that S could have sold $x_{(3)}$ or bought $y_{(3)}$, and so cannot draw any inference on θ_s. In that case, $E(\theta_{\neg m}|\theta_m = \sigma, y_{(3)} - 1 \leq \omega_1 \leq 1 - x_{(3)}) = 0$. The analysis is similar if $\theta_m = -\sigma$. For example, $E(\theta_{\neg m}|\theta_m = -\sigma, -y_{(3)} - 1 \leq \omega_1 \leq x_{(3)} - 1) = -\frac{1}{3}\sigma$.
Next, we display the calculations for the order sizes, $x_{(3)}$ and $y_{(3)}$. Denote $z \equiv \frac{x_{(3)}+y_{(3)}}{2}$. The price conjecture in Equations (3) and (4) lead to the following, starting with the case $m = s$:

- Case 1. If $m = s, \theta_m = \theta_s = \sigma$ and $\theta_{\neg m} = \sigma$ (which occurs with probability $1/2 \times 1/2 \times 1/2 = 1/8$), then S buy $y_{(3)}$ shares so $\omega_1 = y_{(3)} + n$ and

$$(\theta, p_1, \theta - p_1) = \begin{cases} (2\sigma, \frac{4}{3}\sigma, \frac{2}{3}\sigma) & \text{with proba. } z/8 \text{ (i.e., for } -x_{(3)} + 1 - y_{(3)} < n \leq 1) \\ (2\sigma, \sigma, \sigma) & \text{with proba. } (1-z)/8 \text{ (i.e., for } -1 < n \leq -x_{(3)} + 1 - y_{(3)}) \\ (2\sigma, 0, 2\sigma) & \text{with proba. } 0 \text{ (i.e., for } -x_{(3)} - 1 - y_{(3)} < n \leq -1) \end{cases}$$

- Case 2. If $m = s, \theta_m = \theta_s = \sigma$ and $\theta_{\neg m} = -\sigma$ (which occurs with probability $1/2 \times 1/2 \times 1/2 = 1/8$), then again S buy $y_{(3)}$ shares so $\omega_1 = y_{(3)} + n$ and

$$(\theta, p_1, \theta - p_1) = \begin{cases} (0, \frac{4}{3}\sigma, -\frac{4}{3}\sigma) & \text{with proba. } z/8 \text{ (i.e., for } -x_{(3)} + 1 - y_{(3)} < n \leq 1) \\ (0, \sigma, -\sigma) & \text{with proba. } (1-z)/8 \text{ (i.e., for } -1 < n \leq -x_{(3)} + 1 - y_{(3)}) \\ (0, 0, 0) & \text{with proba. } 0 \text{ (i.e., for } -x_{(3)} - 1 - y_{(3)} < n \leq -1) \end{cases}$$

- Case 3. If $m = s, \theta_m = \theta_s = -\sigma$ and $\theta_{\neg m} = \sigma$ (which occurs with probability $1/2 \times 1/2 \times 1/2 = 1/8$), then S sell $y_{(3)}$ shares so $\omega_1 = -y_{(3)} + n$ and

$$(\theta, p_1, \theta - p_1) = \begin{cases} (0, 0, 0) & \text{with proba. } 0 \text{ (i.e., for } 1 < n \leq 1 + x_{(3)} + y_{(3)}) \\ (0, -\sigma, \sigma) & \text{with proba. } (1-z)/8 \text{ (i.e., for } -1 + x_{(3)} + y_{(3)} < n \leq 1 \\ (0, -\frac{4}{3}\sigma, \frac{4}{3}\sigma) & \text{with proba. } z/8 \text{ (i.e., for } -1 < n \leq -1 + x_{(3)} + y_{(3)}) \end{cases}$$

- Case 4. If $m = s, \theta_m = \theta_s = -\sigma$ and $\theta_{\neg m} = -\sigma$ (which occurs with probability $1/2 \times 1/2 \times 1/2 = 1/8$), then again S sell $y_{(3)}$ shares so $\omega_1 = -y_{(3)} + n$ and

$$(\theta, p_1, \theta - p_1) = \begin{cases} (-2\sigma, 0, -2\sigma) & \text{with proba. } z/8 \text{ (i.e., for } 1 < n \leq 1 + x_{(3)} + y_{(3)}) \\ (-2\sigma, -\sigma, -\sigma) & \text{with proba. } (1-z)/8 \text{ (i.e., for } -1 + x_{(3)} + y_{(3)} < n \leq 1 \\ (-2\sigma, -\frac{4}{3}\sigma, -\frac{2}{3}\sigma) & \text{with proba. } 0 \text{ (i.e., for } -1 < n \leq -1 + x_{(3)} + y_{(3)} \end{cases}$$

We consider next the case $m \neq s$:

- Case 5. If $m \neq s$,$\theta_m = \sigma$ and $\theta_s = \sigma$ (which occurs with probability $1/2 \times 1/2 \times 1/2 = 1/8$), then S buy $y_{(3)}$ shares so $\omega_1 = y_{(3)} + n$ and

$$(\theta, p_1, \theta - p_1) = \begin{cases} (2\sigma, \frac{4}{3}\sigma, \frac{2}{3}\sigma) & \text{with proba. } z/8 \text{ (i.e., for } -x_{(3)} + 1 - y_{(3)} < n \leq 1) \\ (2\sigma, \sigma, \sigma) & \text{with proba. } (1-z)/8 \text{ (i.e., for } -1 < n \leq -x_{(3)} + 1 - y_{(3)}) \\ (2\sigma, 0, 2\sigma) & \text{with proba. } 0 \text{ (i.e., for } -x_{(3)} - 1 - y_{(3)} < n \leq -1) \end{cases}$$

- Case 6. If $m \neq s, \theta_m = \sigma$ and $\theta_s = -\sigma$ (which occurs with probability $1/2 \times 1/2 \times 1/2 = 1/8$), then S sell $x_{(3)}$ shares so $\omega_1 = -x_{(3)} + n$ and

$$(\theta, p_1, \theta - p_1) = \begin{cases} (0, \frac{4}{3}\sigma, -\frac{4}{3}\sigma) & \text{with proba. } 0 \text{ (i.e., for } 1 < n \leq 1 + x_{(3)} + y_{(3)}) \\ (0, \sigma, -\sigma) & \text{with proba. } (1-z)/8 \text{ (i.e., for } -1 + x_{(3)} + y_{(3)} < n \leq 1) \\ (0, 0, 0) & \text{with proba. } z/8 \text{ (i.e., for } -1 < n \leq -1 + x_{(3)} + y_{(3)}) \end{cases}$$

- Case 7. If $m \neq s, \theta_m = -\sigma$ and $\theta_s = \sigma$ (which occurs with probability $1/2 \times 1/2 \times 1/2 = 1/8$), then S buy $x_{(3)}$ shares so $\omega_1 = x_{(3)} + n$ and

$$(\theta, p_1, \theta - p_1) = \begin{cases} (0, 0, 0) & \text{with proba. } z/8 \text{ (i.e., for } 1 - x_{(3)} - y_{(3)} < n \leq 1) \\ (0, -\sigma, \sigma) & \text{with proba. } (1-z)/8 \text{ (i.e., for } -1 < n \leq 1 - x_{(3)} - y_{(3)}) \\ (0, -\frac{4}{3}\sigma, \frac{4}{3}\sigma) & \text{with proba. } 0 \text{ (i.e., for } -1 - x_{(3)} - y_{(3)} < n \leq -1) \end{cases}$$

- Case 8. If $m \neq s, \theta_m = -\sigma$ and $\theta_s = -\sigma$ (which occurs with probability $1/2 \times 1/2 \times 1/2 = 1/8$), then S sell $y_{(3)}$ shares so $\omega_1 = -y_{(3)} + n$ and

$$(\theta, p_1, \theta - p_1) = \begin{cases} (-2\sigma, 0, -2\sigma) & \text{with proba. } z/8 \text{ (i.e., for } 1 < n \leq 1 + x_{(3)} + y_{(3)}) \\ (-2\sigma, -\sigma, -\sigma) & \text{with proba. } (1-z)/8 \text{ (i.e., for } -1 + x_{(3)} + y_{(3)} < n \leq 1) \\ (-2\sigma, -\frac{4}{3}\sigma, -\frac{2}{3}\sigma) & \text{with proba. } 0 \text{ (i.e., for } -1 < n \leq -1 + x_{(3)} + y_{(3)}) \end{cases}$$

Collecting the cases such that $\theta_m = \theta_s = \sigma$ (cases 1, 2 and 5) leads to $E[\theta - p_1 | \theta_m = \sigma, \theta_s = \sigma] = \frac{1}{3}\sigma(1-z)$ and $Var[\theta - p_1 | \theta_m = \sigma, \theta_s = \sigma] = \frac{1}{9}\sigma^2(8 + z - z^2)$. Plugging these expressions into the first-order condition for S' profit maximization and imposing rational expectations ($x_i = x_{(3)}$ and $y_i = y_{(3)}$ for all i) yields:

$$y_{(3)} = \frac{E[\theta - p_1 | \theta_m = \sigma, \theta_s = \sigma]}{\gamma Var[\theta - p_1 | \theta_m = \sigma, \theta_s = \sigma]} = \frac{\frac{1}{3}\sigma(1-z)}{\gamma \frac{1}{9}\sigma^2(8 + z - z^2)} = \frac{3(1-z)}{\gamma\sigma(8 + z - z^2)}.$$

Likewise, collecting the cases such that $\theta_m = \theta_s = -\sigma$ (cases 3, 4 and 8) leads to $E[\theta - p_1 | \theta_m = -\sigma, \theta_s = -\sigma] = -\frac{1}{3}\sigma(1-z)$ and $Var[\theta - p_1 | \theta_m = \sigma, \theta_s = \sigma] = \frac{1}{9}\sigma^2(8 + z - z^2)$. Plugging these expressions into the first-order condition for S' profit maximization and imposing rational expectations ($x_i = x_{(3)}$ and $y_i = y_{(3)}$ for all i) yields:

$$-y_{(3)} = \frac{E[\theta - p_1 | \theta_m = \sigma, \theta_s = \sigma]}{\gamma Var[\theta - p_1 | \theta_m = \sigma, \theta_s = \sigma]} = \frac{-\frac{1}{3}\sigma(1-z)}{\gamma \frac{1}{9}\sigma^2(8 + z - z^2)} = -\frac{3(1-z)}{\gamma\sigma(8 + z - z^2)},$$

which is the same equation as in the case $(\theta_m = \sigma, \theta_s = \sigma)$.

Collecting the cases such that $\theta_m = \sigma$ and $\theta_s = -\sigma$ (case 6) leads to $E[\theta - p_1 | \theta_m = \sigma, \theta_s = -\sigma] = -\sigma(1-z)$ and $Var[\theta - p_1 | \theta_m = \sigma, \theta_s = -\sigma] = \sigma^2 z(1-z)$. Plugging these expressions into the first-order condition for S' profit maximization and imposing rational expectations ($x_i = x_{(3)}$ and $y_i = y_{(3)}$ for all i) yields:

$$-x_{(3)} = \frac{E\left[\theta - p_1|\theta_m = \sigma, \theta_s = -\sigma\right]}{\gamma Var\left[\theta - p_1|\theta_m = \sigma, \theta_s = -\sigma\right]} = \frac{-\sigma\left(1-z\right)}{\gamma\sigma^2 z(1-z)} = -\frac{1}{\gamma\sigma z}.$$

Finally, collecting the cases such that $\theta_m = -\sigma$ and $\theta_s = \sigma$ (case 7) leads to $E\left[\theta - p_1|\theta_m = -\sigma, \theta_s = \sigma\right] = \sigma\left(1-z\right)$ and $Var\left[\theta - p_1|\theta_m = -\sigma, \theta_s = \sigma\right] = \sigma^2 z(1-z)$. Plugging these expressions into the first-order condition for S' profit maximization and imposing rational expectations ($x_i = x_{(3)}$ and $y_i = y_{(3)}$ for all i) yields:

$$x_{(3)} = \frac{E\left[\theta - p_1|\theta_m = -\sigma, \theta_s = \sigma\right]}{\gamma Var\left[\theta - p_1|\theta_m = -\sigma, \theta_s = \sigma\right]} = \frac{\sigma\left(1-z\right)}{\gamma\sigma^2 z(1-z)} = \frac{1}{\gamma\sigma z},$$

which is the same equation as in the case $(\theta_m = \sigma, \theta_s = -\sigma)$.

Gathering the different cases and substituting out $z \equiv \frac{x_{(3)}+y_{(3)}}{2}$, investors' first-order conditions yield a system of two equations in $x_{(3)}$ and $y_{(3)}$:

$$\begin{aligned}
x_{(3)} &= \frac{1}{\gamma\sigma\frac{x_{(3)}+y_{(3)}}{2}} \\
y_{(3)} &= \frac{3\left(1-\frac{x_{(3)}+y_{(3)}}{2}\right)}{\gamma\sigma\left(8+\frac{x_{(3)}+y_{(3)}}{2}-\left(\frac{x_{(3)}+y_{(3)}}{2}\right)^2\right)}
\end{aligned}$$

The first equation implies that $y_{(3)} = \frac{2-\gamma\sigma x_{(3)}^2}{\gamma\sigma x_{(3)}}$. Plugging this expression in the second equation and rearranging leads to the quartic equation:

$$1 - \gamma\sigma x_{(3)} - 2\gamma\sigma(1+4\gamma\sigma)x_{(3)}^2 + 2(\gamma\sigma)^2 x_{(3)}^3 + 4(\gamma\sigma)^3 x_{(3)}^4 = 0. \tag{6}$$

The equilibrium is thus characterized by Equation (6), together with the requirement that $x_{(3)} \geq y_{(3)}$. We show next that there exists a unique equilibrium.

Since $y_{(3)} = \frac{2-\gamma\sigma x_{(3)}^2}{\gamma\sigma x_{(3)}}$, $x_{(3)} \geq y_{(3)}$ is equivalent to $x \geq 1/\sqrt{\gamma\sigma}$. Let $g(x) \equiv 1 - \gamma\sigma x - 2\gamma\sigma(1+4\gamma\sigma)x^2 + 2(\gamma\sigma)^2 x^3 + 4(\gamma\sigma)^3 x^4$. We show next that g admits exactly one root in the interval $\left[1/\sqrt{\gamma\sigma}, 1\right]$, implying that there exists a unique equilibrium. The second derivative of g, $g''(x) = -4\gamma\sigma(1+4\gamma\sigma) + 12(\gamma\sigma)^2 x + 48(\gamma\sigma)^3 x^2$, is a quadratic function which admits two roots: one root, $(-1-\sqrt{1+48(1+4\gamma\sigma)/9})/(8\gamma\sigma)$, is negative and the other, $x_+ \equiv (-1+\sqrt{1+48(1+4\gamma\sigma)/9})/(8\gamma\sigma)$, is between 0 and 1. It follows that $g''(x) \leq 0$ for x in $[0, x_+]$ and $g''(x) \geq 0$ for x in $[x_+, 1]$, and so that g' is decreasing over $[0, x_+]$ and increasing over $[x_+, 1]$, where $g'(x) = -\gamma\sigma - 4\gamma\sigma(1+4\gamma\sigma)x + 6(\gamma\sigma)^2 x^2 + 16(\gamma\sigma)^3 x^3$. Given that $g'(0) = -\gamma\sigma < 0$ and $g'(1) = \gamma\sigma(-5-10\gamma\sigma+16(\gamma\sigma)^2) = \gamma\sigma(5(-1+(\gamma\sigma)^2)+10\gamma\sigma(-1+\gamma\sigma)+(\gamma\sigma)^2) > 0$ (from Assumption 1, each term in brackets is positive), there exists a unique x_* in $[x_+, 1]$ such that $g'(x) \leq 0$ for x in $[0, x_*]$ and $g'(x) \geq 0$ for $[x_*, 1]$. This implies in turn that g decreases over $[0, x_*]$ and increases over $[x_*, 1]$. Finally, observing that $g(1/\sqrt{\gamma\sigma}) < 0$ and $g(1) > 0$, g admits a unique root, $x_{(3)}$, in the interval $\left[1/\sqrt{\gamma\sigma}, 1\right]$. Hence, there exists a unique equilibrium.

A.4 Corollary 7 - Price informativeness

1. **Both m and s are common knowledge**
   When m and s are common knowledge, price informativeness is given by:

$$
\begin{aligned}
E\left(Var\left(\theta|p_1,p_0\right)\right) &= Pr(m=s)\,E\left(\left(\theta-p_1\right)^2|m=s\right)\\
&\quad +Pr(m\neq s)\,E\left(\left(\theta-p_1\right)^2|m\neq s\right)\\
&= \frac{1}{2}\sigma^2+\frac{1}{2}\sigma^2(1-x_{(1)})\\
&= \sigma^2\left(1-\frac{1}{2}x_{(1)}\right)
\end{aligned}
$$

   The ex-ante uncertainty is $Var(\theta)=2\sigma^2$. It follows that $PI_{(1)}\equiv Var\left(E\left(\theta|p_1,p_0\right)\right)=Var(\theta)-E\left(Var\left(\theta|p_1,p_0\right)\right)=2\sigma^2-\sigma^2\left(1-\frac{1}{2}x_{(1)}\right)=\sigma^2\left(1+\frac{1}{2}x_{(1)}\right)$. When $x=0$, half of this uncertainty is resolved through the publication of θ_m in the $t=0$ price. When $x=1$, all the uncertainty is resolved for the case $m\neq s$, while only half of the uncertainty is resolved for the case $m=s$.

2. **Only m is common knowledge**
   When only m is common knowledge, price informativeness is given by:

$$
\begin{aligned}
E\left(Var\left(\theta|p_1,p_0\right)\right) &= Pr(m=s)\,E\left(\left(\theta-p_1\right)^2|m=s\right)\\
&\quad +Pr(m\neq s)\,E\left(\left(\theta-p_1\right)^2|m\neq s\right)\\
&= \frac{1}{2}\left[\begin{array}{c} Pr(m=s,\theta_s=\sigma)\,E\left(\left(\theta-p_1\right)^2|m=s,\theta_s=\sigma\right)\\ +Pr(m=s,\theta_s=-\sigma)\,E\left(\left(\theta-p_1\right)^2|m=s,\theta_s=-\sigma\right)\end{array}\right]\\
&\quad +\frac{1}{2}\left[\begin{array}{c} Pr(m\neq s,\theta_s=\sigma)\,E\left(\left(\theta-p_1\right)^2|m\neq s,\theta_s=\sigma\right)\\ +Pr(m\neq s,\theta_s=-\sigma)\,E\left(\left(\theta-p_1\right)^2|m\neq s,\theta_s=-\sigma\right)\end{array}\right]\\
&= \frac{1}{2}\left[\frac{1}{2}\left(\left(\frac{2}{3}\sigma\right)^2\frac{x_{(2)}}{2}+\sigma^2(1-x_{(2)})+\left(\frac{4}{3}\sigma\right)^2\frac{x_{(2)}}{2}\right)+\frac{1}{2}\left(\left(\frac{4}{3}\sigma\right)^2\frac{x_{(2)}}{2}+\sigma^2(1-x_{(2)})+\left(\frac{2}{3}\right.\right.\right.\\
&\quad +\frac{1}{2}\left[\frac{1}{2}\left(\sigma^2(1-x_{(2)})+\left(\frac{2}{3}\sigma\right)^2\frac{x_{(2)}}{2}\right)+\frac{1}{2}\left(\left(\frac{2}{3}\sigma\right)^2\frac{x_{(2)}x}{2}+\sigma^2(1-x_{(2)})\right)\right]\\
&= \frac{1}{2}\left[\left(\left(\frac{2}{3}\sigma\right)^2\frac{x_{(2)}}{2}+\sigma^2(1-x_{(2)})+\left(\frac{4}{3}\sigma\right)^2\frac{x_{(2)}}{2}\right)\right]\\
&\quad +\frac{1}{2}\left[\left(\sigma^2(1-x_{(2)})+\left(\frac{2}{3}\sigma\right)^2\frac{x_{(2)}}{2}\right)\right]\\
&= \left(\frac{2}{3}\sigma\right)^2\frac{x_{(2)}}{2}+\sigma^2(1-x_{(2)})+\frac{1}{2}\left(\frac{4}{3}\sigma\right)^2\frac{x_{(2)}}{2}\\
&= \sigma^2(1-x_{(2)})+x_{(2)}\sigma^2\frac{2}{3}\\
&= \sigma^2\left(1-\frac{1}{3}x_{(2)}\right)
\end{aligned}
$$

   Therefore $PI_{(2)}\equiv Var\left(E\left(\theta|p_1,p_0\right)\right)=Var(\theta)-E\left(Var\left(\theta|p_1,p_0\right)\right)=2\sigma^2-\sigma^2\left(1-\frac{1}{3}x_{(2)}\right)=\sigma^2\left(1+\frac{1}{3}x_{(2)}\right)$. As before, when $x=0$, half of the total uncertainty is resolved through the publication of θ_m in the $t=0$ price. When $x=1$, an additional one sixth ($\frac{1}{3}\sigma^2/(2\sigma^2)=\frac{1}{6}$) of the total uncertainty is resolved through the trading by S.

3. **Neither m nor s are common knowledge**
When neither m nor s are common knowledge, price informativeness is given by:

$$
\begin{aligned}
E\left(Var\left(\theta|p_1,p_0\right)\right) &= Pr(m=s)\,E\left(\left(\theta-p_1\right)^2|m=s\right)\\
&\quad +Pr(m\neq s)\,E\left(\left(\theta-p_1\right)^2|m\neq s\right)\\
&= \frac{1}{2}\left[\begin{array}{c} Pr(m=s,\theta_s=\sigma,\theta_{\neg m}=\sigma)\,E\left(\left(\theta-p_1\right)^2|m=s,\theta_s=\sigma,\theta_{\neg m}=\sigma\right)\\ +Pr(m=s,\theta_s=\sigma,\theta_{\neg m}=-\sigma)\,E\left(\left(\theta-p_1\right)^2|m=s,\theta_s=\sigma,\theta_{\neg m}=-\sigma\right)\\ +Pr(m=s,\theta_s=-\sigma,\theta_{\neg m}=\sigma)\,E\left(\left(\theta-p_1\right)^2|m=s,\theta_s=-\sigma,\theta_{\neg m}=\sigma\right)\\ +Pr(m=s,\theta_s=-\sigma,\theta_{\neg m}=-\sigma)\,E\left(\left(\theta-p_1\right)^2|m=s,\theta_s=-\sigma,\theta_{\neg m}=-\sigma\right)\end{array}\right]\\
&\quad +\frac{1}{2}\left[\begin{array}{c} Pr(m\neq s,\theta_s=\sigma,\theta_m=\sigma)\,E\left(\left(\theta-p_1\right)^2|m\neq s,\theta_s=\sigma,\theta_m=\sigma\right)\\ +Pr(m\neq s,\theta_s=\sigma,\theta_m=-\sigma)\,E\left(\left(\theta-p_1\right)^2|m\neq s,\theta_s=\sigma,\theta_m=-\sigma\right)\\ +Pr(m\neq s,\theta_s=-\sigma,\theta_m=\sigma)\,E\left(\left(\theta-p_1\right)^2|m\neq s,\theta_s=-\sigma,\theta_m=\sigma\right)\\ +Pr(m\neq s,\theta_s=-\sigma,\theta_m=-\sigma)\,E\left(\left(\theta-p_1\right)^2|m\neq s,\theta_s=-\sigma,\theta_m=-\sigma\right)\end{array}\right]\\
&= \frac{1}{2}\left[\begin{array}{c} \frac{1}{4}\left(\left(\frac{2}{3}\sigma\right)^2\frac{x+y}{2}+\sigma^2\left(1-\frac{x+y}{2}\right)\right)+\frac{1}{4}\left(\left(\frac{4}{3}\sigma\right)^2\frac{x+y}{2}+\sigma^2\left(1-\frac{x+y}{2}\right)\right)\\ +\frac{1}{4}\left(\left(\frac{2}{3}\sigma\right)^2\frac{x+y}{2}+\sigma^2\left(1-\frac{x+y}{2}\right)\right)+\frac{1}{4}\left(\left(\frac{4}{3}\sigma\right)^2\frac{x+y}{2}+\sigma^2\left(1-\frac{x+y}{2}\right)\right)\end{array}\right]\\
&\quad +\frac{1}{2}\left[\begin{array}{c} \frac{1}{4}\left(\left(\frac{2}{3}\sigma\right)^2\frac{x+y}{2}+\sigma^2\left(1-\frac{x+y}{2}\right)\right)+\frac{1}{4}\left(\sigma^2\left(1-\frac{x+y}{2}\right)\right)\\ \frac{1}{4}\left(\sigma^2\left(1-\frac{x+y}{2}\right)\right)+\frac{1}{4}\left(\left(\frac{2}{3}\sigma\right)^2\frac{x+y}{2}+\sigma^2\left(1-\frac{x+y}{2}\right)\right)\end{array}\right]\\
&= \frac{1}{2}\left[\frac{1}{2}\left(\left(\frac{2}{3}\sigma\right)^2\frac{x+y}{2}+\sigma^2\left(1-\frac{x+y}{2}\right)\right)+\frac{1}{2}\left(\left(\frac{4}{3}\sigma\right)^2\frac{x+y}{2}+\sigma^2\left(1-\frac{x+y}{2}\right)\right)\right]\\
&\quad +\frac{1}{2}\left[\frac{1}{2}\left(\left(\frac{2}{3}\sigma\right)^2\frac{x+y}{2}+\sigma^2\left(1-\frac{x+y}{2}\right)\right)+\frac{1}{2}\left(\sigma^2\left(1-\frac{x+y}{2}\right)\right)\right]\\
&= \frac{1}{2}\left[\frac{10}{9}\sigma^2\frac{x+y}{2}+\sigma^2\left(1-\frac{x+y}{2}\right)\right]\\
&\quad +\frac{1}{2}\left[\frac{2}{9}\sigma^2\frac{x+y}{2}+\sigma^2\left(1-\frac{x+y}{2}\right)\right]\\
&= \frac{2}{3}\sigma^2\frac{x+y}{2}+\sigma^2\left(1-\frac{x+y}{2}\right)\\
&= \sigma^2\left(1-\frac{1}{3}\frac{x+y}{2}\right)
\end{aligned}
$$

Hence $PI_{(3)} \equiv Var\left(E\left(\theta|p_1,p_0\right)\right) = Var(\theta) - E\left(Var\left(\theta|p_1,p_0\right)\right) = 2\sigma^2 - \sigma^2\left(1-\frac{1}{3}\frac{x+y}{2}\right) = \sigma^2\left(1+\frac{1}{3}\frac{x+y}{2}\right)$. As before, when $x=y=0$, half of the total uncertainty is resolved through the publication of θ_m in the $t=0$ price. If $x=y=1$ were possible, then total uncertainty would be further reduced by one sixth.

Ranking of price informativeness
We show that $PI_{(1)} > PI_{(3)}$. In the proof of Proposition 4, we establish that $x_{(3)} > 1/\sqrt{\gamma\sigma} = x_{(1)}$. This inequality implies that $1/(\gamma\sigma x_{(3)}) < 1/\sqrt{\gamma\sigma} = x_{(1)}$. Moreover, we show, also in the proof of Proposition 4, that $(y_{(3)}+x_{(3)})/2 = 1/(\gamma\sigma x_{(3)})$. Combining both expressions leads to $(y_{(3)}+x_{(3)})/2 < x_{(1)}$ and so to $x_{(1)} > (y_{(3)}+x_{(3)})/3$. Hence, $PI_{(1)} > PI_{(3)}$. Note also that $y_{(3)} = \frac{2}{\gamma\sigma x_{(3)}} - x_{(3)} < 2/\sqrt{\gamma\sigma} - 1/\sqrt{\gamma\sigma} = 1/\sqrt{\gamma\sigma} = x_{(1)}$ so $0 < y_{(3)} < x_{(1)} < x_{(3)} < 1$.
We show next that $PI_{(2)} > PI_{(3)}$. Given the expressions for $PI_{(2)}$ and $PI_{(3)}$, this inequality is equivalent to $\frac{x_{(3)}+y_{(3)}}{2} < x_{(2)}$. We employ again two results established in the proof of Proposition 4: $\frac{x_{(3)}+y_{(3)}}{2} = \frac{1}{\gamma\sigma x_{(3)}}$ and $x_{(3)} > 1/\sqrt{\gamma\sigma} = x_{(1)}$. They imply that $\frac{x_{(3)}+y_{(3)}}{2} < 1/\sqrt{\gamma\sigma} = x_{(1)}$, so it suffices

to show that $x_{(1)} < x_{(2)}$. To do so, we show that $f(x_{(1)}) > 0$ where f is the decreasing function defined in the proof of Proposition 2, of which $x_{(2)}$ is a root: $f(x_{(1)}) = 9 - 6x_{(1)} - 5\gamma\sigma x_{(1)}^2 + 4\gamma\sigma x_{(1)}^3$ $=9 - 6(1/\sqrt{\gamma\sigma}) - 5\gamma\sigma(1/\sqrt{\gamma\sigma})^2 + 4\gamma\sigma(1/\sqrt{\gamma\sigma})^3 = 4 - 2/\sqrt{\gamma\sigma} > 0$ for $\gamma\sigma > 3$. Hence, $f(x_{(1)}) > 0 = f(x_{(2)})$, which in turn implies $x_{(1)} < x_{(2)}$. Thus, $PI_{(2)} > PI_{(3)}$.

Intuition

S are most aggressive in case (2) when $m \neq s$; that is, when they have an information advantage but when market makers don't know this. Intuitively, for market makers the order flow appears less informative since unconditionally there is a 50% chance that it is pure noise (when $m = s$ so that speculators have no information advantage). The speculators respond to this by trading more aggressively when they do have an information advantage (i.e., when $m \neq s$).

With uncertainty about what's in the price (case (3)) and when $\theta_s \neq \theta_m$, speculators understand that they have an information advantage (i.e., that it must be $m \neq s$) and thus trade almost as aggressively as in case (2).[23] When $\theta_s = \theta_m$, speculators are unsure whether their information is novel (i.e., $m \neq s$) or stale (i.e., $m = s$) and therefore trade less aggressively. Lastly, when both m and s are common knowledge (case (1)), speculators' trading aggressiveness when $m \neq s$ lies between the ones for $\theta_s \neq \theta_m$ and $\theta_s = \theta_m$ with uncertainty about what's in the price.

[23] They trade slightly less aggressively because the equilibrium price function in case (3) entails a larger price impact compared to the one in case (2).