Informed trading and stock market efficiency*

Taneli Mäkinen†
Banca d'Italia

Abstract

Information content of stock prices is analysed without imposing strong restrictions on traders' preferences and the distribution of dividends. Noise in the information contained in equilibrium prices arises from endogenous asset supply, which offsets price movements due to informed trading. Informativeness of stock prices is increasing in the wealth of the informed traders and decreasing in the risk-free rate as stock prices respond more strongly to information held by informed traders when they take larger positions in stocks.

JEL codes: D53, D82, G14.
Keywords: asset markets, asymmetric information, rational expectations equilibrium.

1 Introduction

Stock prices do not adjust instantaneously to new information about fundamentals. In a survey of the literature on the reaction of stock prices to earnings announcements, Ball (1978) reports consistent evidence of post-earnings-announcement drift, i.e. price under-reaction. Similarly, Fama (1998) concludes that post-earnings-announcement drift is 'above suspicion' as it 'has survived robustness checks, including extension to more recent data'.

The theoretical literature on how information gets incorporated into stock prices builds on the contributions of Grossman and Stiglitz (1976) and Kyle (1985). Grossman and Stiglitz (1976) study a competitive stock market in

*I am grateful to Marcello Pericoli, Giuseppe Grande, Gabriele Zinna, Marco Taboga and participants at Banca d'Italia Lunch Seminar for helpful comments and suggestions. The views expressed herein are those of the author and not necessarily those of Banca d'Italia. All remaining errors are mine.

†E-mail: taneli.makinen@esterni.bancaditalia.it

which some traders possess superior information about the stock's fundamental value. Kyle (1985), in turn, analyses the speed at which information is incorporated into prices when an informed trader internalises the price impact of their trading. In both frameworks, to escape from the domain of no trade theorems (see, e.g., Aumann, 1976) and induce less informed traders to trade, the existence of noise traders is postulated. Due to noise traders, less informed investors face a less severe adverse selection problem as prices not only reflect informed trading. Given that noise traders' motives for trading are not explicitly modelled, these models are not ideal for analysing the determinants of the information content of stock prices. Moreover, both Grossman and Stiglitz (1976) and Kyle (1985) impose strong restrictions on traders' preferences and dividend processes.

The present study proposes a theoretical framework in which the informativeness of stock prices can be studied for a wide class of preferences and dividend processes. Moreover, the framework does not feature noise traders, yet less informed traders are willing to trade as not all equilibrium prices fully reveal the information held by the more informed traders. The model is used to study how market conditions affect the informativeness of stock prices.

In the model, risk-averse traders invest their wealth into a risk-free and a risky asset. The risk-free asset is in infinitely elastic supply whereas the risky asset is supplied endogenously by a representative firm. There are two types, informed and uninformed, of traders. Informed traders receive a signal correlated with the payoff of the risky asset before submitting their demand schedules for the two assets. Consequently, equilibrium prices potentially transmit information from the informed to the uninformed traders. However, even though there is no noise trading, not all equilibrium prices fully reveal the signal of the informed traders. This is due to supply of the risky asset responding to equilibrium prices, thereby offsetting price movements due to informed trading. In other words, the endogeneity of the supply of the risky asset introduces noise to the information revealed by equilibrium prices.

As regards how market conditions affect the informativeness of the stock price, two findings emerge. First, when the informed traders' preferences are characterised by decreasing absolute risk aversion, the informativeness of the stock price is increasing in the wealth of the informed traders. Decreasing absolute risk aversion ensures that informed traders' demand for the risky asset is increasing in their wealth. Consequently, aggregate demand for the risk asset varies more with the informed traders' signal when their wealth rises. Therefore, the probability that the stock price reveals the signal of the informed traders increases. Second, when the supply of the risky asset is strictly positive, the informativeness of stock prices is decreasing in the risk-free rate. Traders take larger positions in the risky asset when the risk-free rate falls. For this reason, the informativeness of the stock price is falling in the risk-free rate.

Confronting the predictions of the model with data provides suggestive evidence for the theoretical results. Employing US data, the dependence of serial correlation in stock returns is studied. Serial correlation in stock returns can be expected to increase when information is incorporated into stock prices more gradually, i.e. when stock prices are less informative. It is found that serial correlation in returns is increasing in the risk-free rate and in funding illiquidity, measured by the Treasury bill rate and the spread between commercial paper and Treasury bill rates, respectively. As funding liquidity determines investors' ability to take positions in different assets, its effect can be expected to be similar to investors' wealth in the theoretical model.

This paper is related to the literature on information transmission via asset prices under asymmetric information. Grossman and Stiglitz (1980) identify four determinants of the information content of equilibrium prices. Namely, in their model, the informativeness of stock prices is decreasing in traders' absolute risk aversion and the intensity of noise trading while it is increasing in the intensity of informed trading and the precision of informed traders' information. Interestingly, lower absolute risk aversion leads to more informative stock prices as traders take larger positions in the risky asset. Also in my model, the informativeness of stock prices depends crucially on the size of traders' positions. In the framework of Kyle (1985), on the other hand, stock prices are more informative when informed traders receive more precision information. There are two main differences between my model and those of Grossman and Stiglitz (1980) and Kyle (1985). While traders in Grossman and Stiglitz (1980) have exponential utility functions and in Kyle (1985) are risk-neutral, I only place weak restrictions on traders' preferences. Second, my framework does not feature noise traders but partially-revealing equilibrium prices arise from endogenous supply of the risky asset.

Among studies building on the analysis of Grossman and Stiglitz (1980), a few are closely related to this paper. Ausubel (1990) shows the existence of partially-revealing rational expectations equilibrium without imposing strong restrictions on preferences and payoff distributions. However, Ausubel (1990) is concerned with the existence of equilibrium and does not study the determinants of stock price informativeness. Wang (1994), in turn, models noise in equilibrium prices as arising from private investment opportunities. Similarly, Dow and Rahi (2003) study informed trading in the presence of a feedback effect on investment without noise traders. However, both Wang (1994) and

Dow and Rahi (2003) conduct their analysis in an environment with exponential utility functions and normally distributed payoffs.

The contribution of this paper is twofold. First, a framework for analysing the information content of stock prices which does not impose strong restrictions on preferences or payoff distributions is developed. In the model, endogenous supply of assets introduces noise into the information revealed by equilibrium prices, obviating the need for noise traders. Second, the model is used to study determinants of stock price informativeness which by design do not play a role in previous studies.

2 Model

There are two dates, 0 and 1. At date 1, there are S possible states of the world, indexed by $s \in \{1, \ldots, S\}$. There is a single consumption good. The economy is populated by two groups of agents, called informed (I) and uninformed traders (U). The two groups differ in terms of their information about the state of the world and their endowments. The measure of uninformed agents is normalised to 1 whereas the measure of informed traders is λ.

Traders maximise expected utility over date-1 consumption. All traders share the same utility function $u(\cdot)$, which is strictly increasing, strictly concave and has a coefficient of relative risk aversion less or equal than unity. Initially, the two groups of traders hold a common prior probability distribution over the states of nature, attaching probability π_s to state s obtaining at date 1. Informed traders receive additional information about the state in the form of a signal $z \in \mathbb{R}$ with the conditional density (or probability mass) function $f(z \mid s)$. The family of densities $\{f(\cdot \mid s)\}$ has the strict monotone likelihood ratio property.[1]

Two assets are traded in the economy. There is a risk-free asset with gross return $\bar{R}$, the price of which is normalised to 1. The risk-free asset is in infinitely elastic supply. The other asset is risky, yielding a payoff of $\theta_s \geq 0$ units of the consumption good in state s. The risky asset is supplied endogenously. Namely, there is a representative firm in the economy, holding 1 unit of the consumption good at date 0. The firm can invest in a risky technology with the state-contingent payoff θ_s and a risk-free technology yielding $\bar{R}$. Specifically, the firm chooses $\omega \in [0, 1]$ yielding an output at date-1 of $(1-\omega)\bar{R} + \omega\theta_s$. Hence, the supply of risky assets in the economy is given by ω. The firm's objective is to maximise the market value of its output. The two assets are traded in a competitive market.

[1] That is, for every $z' > z$ and $s' > s$, $f(z' \mid s')f(z \mid s) > f(z' \mid s)f(z \mid s')$.

At date 0, each informed trader is endowed with w units of the consumption good. Each uninformed trader, on the other hand, is endowed with 1 share of the representative firm. However, these shares as such are not publicly traded.

Traders' information about the state of the world is complemented by market prices. Namely, traders' information sets include the price of the risky asset p, which can potentially provide further information about the state s. On the other hand, the investment choice ω is not known to the traders when they submit their demands for the two assets. To summarise, the information sets of the informed and uninformed traders are $\mathcal{I}^I = \{p, z\}$ and $\mathcal{I}^U = \{p\}$, respectively.

2.1 Discussion of assumptions

A coefficient of relative risk aversion less than unity ensures that informed traders' demand for the risky asset is increasing in the signal z and that uninformed traders' demand is decreasing in the price p. As uninformed traders own the representative firm, their wealth is increasing in p. When the coefficient of relative risk aversion is less than unity, the wealth effect of higher p is moderate enough such that uninformed traders' demand curves for the risky asset are downward-sloping. The monotonicity of informed traders' demand in the signal, on the other hand, ensures the tractability of learning from equilibrium prices.

The monotone likelihood ratio property of the signal densities implies that the informed traders' expectation of the payoff of the risky asset is increasing in the signal. This allows the uninformed traders to infer the realization of the signal whenever the equilibrium price reveals the informed traders' expectation of the payoff.

The representative firm chooses its investment in the two technologies, determining the supply of the risky asset, when observing the price of the risky asset. For this reason the supply of the risky asset depends on its price. If one would like to obviate the need for equity issuance to respond contemporaneously to the stock price, one could replace the representative firm with a set of risk-neutral investors following a portfolio rebalancing strategy. Endowing these investors with risky assets and prohibiting them from short selling would deliver an asset supply identical to that solving the optimisation problem of the representative firm. Under this alternative assumption, the analogue of traders not knowing the investment choice of the representative firm would be the unobservability of the risk-neutral traders' holdings of the risky asset.

The endogenous supply of the risky asset serves two purposes. Firstly, the endogeneity introduces a feedback from stock prices to aggregate investment, an empirically supported mechanism.[2] Secondly, the varying supply ensures that the price of the risky asset does not necessarily reveal the signal of the informed traders. That is, the stock price can be partially-revealing even though the environment features no exogenous noise trading.

To preserve the partially-revealing nature of the stock price, the investment choice of the representative firm is not observed by the traders when asset trading takes place. The informed traders, however, can infer the investment choice from the equilibrium price. This shows that the informed traders have superior information not only about the payoff the risky asset, but also about the choices of the firm issuing the asset. If the shares of the representative firm were held by the informed traders, ω could be observed directly by the owners of the firm. Nevertheless, the assumption that the uninformed firms own the representative firm is maintained as it allows to study the effect of changes in the wealth of the informed traders in a more straightforward manner. It is also worth pointing out the the unobservability of the investment choice of the representative firm is equivalent to the unobservability of the aggregate supply of risky assets. If one were to introduce additional groups of traders, such as risk-neutral investors following a portfolio rebalancing strategy as outlined above, the assumption that the uninformed traders do not observe the aggregate supply of risky assets would be natural.

The non-tradability of the shares of the representative firm can be justified by viewing the firm as the aggregate productive sector of the economy. At date 0, the number of risky investment projects undertaken in the economy is determined by the stock price, reflecting the agents' willingness to bear risk. The firms investing in the risky technology issue equity whereas the firms investing in the risk-free technology issue debt. For this reason, the firms' investment in the risky technology determines the supply of the risky asset.

3 Equilibrium

Let me first describe the problems faced by the two groups of traders and the representative firm. In what follows, the stochastic payoff of the risky asset will be denoted with $\tilde{\theta}$. An informed trader's demand for the risky asset x^I solves

$$\max_x \mathbb{E}[u(\bar{R}w + (\tilde{\theta} - p\bar{R})x) \,|\, z, p = \mathcal{P}(z)], \tag{1}$$

[2]Chen, Goldstein, and Jiang (2007) find that informative stock price movements affect corporate investment. Polk and Sapienza (2009), on the other hand, discover that also random movements in stock prices influence firms' investment decisions.

where date-1 consumption $\bar{R}w + (\tilde{\theta} - p\bar{R})x^I$ follows from their binding budget constraint. Similarly, an uninformed trader chooses their demand for the risky asset x^U by solving

$$\max_x \mathbb{E}[u(\bar{R}[\omega p + (1-\omega)] + (\tilde{\theta} - p\bar{R})x) \mid p = \mathcal{P}(z)]. \tag{2}$$

The representative firm's investment, in turn, solves

$$\max_\omega [\omega p + (1-\omega)] \tag{3}$$

when observing the price of the risky asset p.

Rational expectations equilibrium requires the optimality of traders' choices when they form expectations about the payoff of the risky asset conditional on the information contained in the equilibrium price.

Definition 1. *A rational expectations equilibrium is a pair of demand schedules* $\{x^I(p,z), x^U(p)\}$*, an investment schedule* $\omega(p)$ *and a price functional* $\mathcal{P}(z)$ *such that*

1. $x^I(p,z)$ *and* $x^U(p)$ *solve the informed and uninformed trader's problem in* (1) *and* (2)*, respectively;*
2. $\omega(p)$ *solves the representative firm's problem in* (3)*;*
3. *the market for the risky asset clears*

$$\lambda x^I(p,z) + x^U(p) = \omega(p). \tag{4}$$

Note that the definition imposes the plausible restriction that the equilibrium price cannot contain information about the state of the world beyond the signal received by the informed traders. This implies that the equilibrium price does not provide additional information about the state of the world to the informed traders. For this reason, hereafter, the equilibrium price is omitted from the informed traders' information set.

The following lemmas characterise the information content of equilibrium prices. First, it is shown that the informed traders' demand for the risky asset is increasing in the signal z. Therefore, knowledge of the quantity demanded by the informed traders allows the uninformed traders to infer the realisation of the signal. Second, the extent to which the equilibrium price reveals the signal received by the informed traders is characterised.

Lemma 1. *Informed traders' demand for the risky asset is strictly increasing in the signal* z*.*

Proof. Given that the family of signal densities has the monotone likelihood ratio property, $F(s \mid z)$ first-order stochastically dominates $F(s \mid z')$ for all $z > z'$. Consequently, by Theorem 2 in Fishburn and Porter (1976), the informed traders' demand is increasing in the signal z given that their coefficient of relative risk aversion is less than 1. For completeness, a proof adapted to the present setting is provided.

First note that the informed trader's objective is concave in their investment in the risky asset x as

$$\frac{\partial^2}{\partial x^2}\mathbb{E}[u(\bar{R}w+(\tilde{\theta}-p\bar{R})x) \mid z] = \mathbb{E}[u''(\bar{R}w+(\tilde{\theta}-p\bar{R})x)(\tilde{\theta}-p\bar{R})^2 \mid z] < 0, \quad (5)$$

by the strict concavity of $u(\cdot)$. Hence, optimal choice satisfies

$$\mathbb{E}[u'(\bar{R}w + (\tilde{\theta} - p\bar{R})x)(\tilde{\theta} - p\bar{R}) \mid z] = 0. \quad (6)$$

Due to the strict concavity of the objective, if

$$\mathbb{E}[u'(\bar{R}w+(\tilde{\theta}-p\bar{R})x)(\tilde{\theta}-p\bar{R}) \mid z'] < \mathbb{E}[u'(\bar{R}w+(\tilde{\theta}-p\bar{R})x)(\tilde{\theta}-p\bar{R}) \mid z] = 0, \quad (7)$$

then $x^I(p, z) > x^I(p, z')$.

To show that the inequality in (7) holds for $z > z'$, it is sufficient to prove that $g(\theta, x) := u'(\bar{R}w + (\tilde{\theta} - p\bar{R})x)(\tilde{\theta} - p\bar{R})$ is increasing in θ. Differentiating g with respect to θ yields

$$\frac{\partial g(\theta, x)}{\partial \theta} = u'(\bar{R}w + (\tilde{\theta} - p\bar{R})x) + u''(\bar{R}w + (\tilde{\theta} - p\bar{R})x)(\tilde{\theta} - p\bar{R})x \quad (8)$$

Rearranging, one obtains

$$\frac{\partial g(\theta, x)}{\partial \theta} > 0 \quad (9)$$

$$\Leftrightarrow \mathcal{R}(c) < 1 + \mathcal{A}(c)\bar{R}w, \quad (10)$$

where $c = \bar{R}w + (\tilde{\theta} - p\bar{R})x$, $\mathcal{A}$ denotes traders' coefficient of absolute risk aversion and $\mathcal{R}$ their coefficient of relative risk aversion. Clearly, for $\mathcal{R}(c) \leq 1$, (10) holds. Given that $F(s \mid z)$ first-order stochastically dominates $F(s \mid z')$ for all $z > z'$, the fact that g is increasing in θ implies that (7) holds. Consequently, the informed traders' demand is strictly increasing in z. □

Lemma 1 implies that knowledge of the informed traders' demand allows the uninformed traders to infer the realisation of the signal. Making use of this invertibility the information content of equilibrium prices can be characterised as follows.

Lemma 2. *Equilibrium prices can be partitioned into a set of prices which fully reveal the signal of the informed traders and a set of partially-revealing prices.*

Proof. Consider first the problem of the representative firm. To maximise the market value of its output, its investment policy satisfies

$$\omega(p) = \begin{cases} 0 & \text{if } p < 1 \\ \omega \in [0,1] & \text{if } p = 1 \\ 1 & \text{if } p > 1. \end{cases} \tag{11}$$

Consequently, when either $p < 1$ or $p > 1$, the uninformed traders have no uncertainty about the supply of risky assets and can infer the demand of the informed traders from the market clearing condition (4). In this case, given that informed traders' demand is strictly increasing in the signal, the equilibrium price reveals the signal realisation. On the other hand, when $p = 1$, the supply of risky assets can vary between 0 and 1. Thus, if there exists at least two distinct signals z and z' such that $\lambda x^I(1,z) + x^U(1) \in [0,1]$ and $\lambda x^I(1,z') + x^U(1) \in [0,1]$, the price $p = 1$ does not fully reveal the signal of the informed traders. The information provided by the price in this case is given by $\{z \mid \lambda x^I(1,z) + x^U(1) \in [0,1]\}$. □

Intuitively, the equilibrium price does not necessarily reveal the demand of the informed traders as the supply of shares responds to the equilibrium price, offsetting price movements due to informed trading. Note however that, depending on the model primitives, either one of the two sets of equilibrium prices identified by Lemma 2 can be empty. That is, all equilibrium prices can either fully reveal the demand of the informed traders or be partially-revealing.[3]

Having characterised the information content of equilibrium prices, let me turn to constructing the equilibrium price functional. Consider first the demand schedule of the informed traders. Given that the equilibrium price provides no additional information to the informed traders, the shape of their demand schedule is simply determined by the relative strengths of substitution and income effects.

Lemma 3. *Informed traders' demand for the risky asset x^I is strictly decreasing in its relative price p.*

[3] In the latter case, the equilibrium price is always 1 and conveys no additional information about z to the uninformed traders.

Proof. Implicitly differentiating the first-order condition (6) yields

$$\begin{aligned}
&-\bar{R}\mathbb{E}[u'(\bar{R}w + (\tilde{\theta} - p\bar{R})x) \mid z] \\
&+ \bar{R}(\omega - x)\mathbb{E}[u''(\bar{R}w + (\tilde{\theta} - p\bar{R})x)(\tilde{\theta} - p\bar{R}) \mid z] \\
&+ \mathbb{E}[u''(\bar{R}w + (\tilde{\theta} - p\bar{R})x)(\tilde{\theta} - p\bar{R})^2 \mid z]\frac{\partial x}{\partial p} = 0.
\end{aligned} \tag{12}$$

The first two terms can be combined to

$$\begin{aligned}
-\bar{R}\mathbb{E}[u'(\bar{R}w + (\tilde{\theta} - p\bar{R})x)(1 - \mathcal{R}(\bar{R}w + (\tilde{\theta} - p\bar{R})x) \\
+ \mathcal{A}(\bar{R}w + (\tilde{\theta} - p\bar{R})x)\bar{R}w)].
\end{aligned} \tag{13}$$

Note that (13) is strictly negative when $\mathcal{R}(\cdot) \leq 1$. Thus, $\partial x/\partial p < 0$ if the coefficient of relative risk aversion is less or equal than one. □

Determining the shape of uninformed traders' demand schedule requires taking into consideration the information content of equilibrium prices and the wealth effect associated with changes in the price of the risky asset. For fully-revealing equilibrium prices, the following obtains.

Lemma 4. *Uninformed traders' demand for the risky asset x^U is strictly decreasing in its relative price p for all $p \neq 1$.*

Proof. By Lemma 2 all equilibrium prices $p \neq 1$ reveal the signal received by the informed traders. Thus, for these prices, the information sets of the informed and the uninformed traders coincide. Then, differentiating the uninformed traders' first-order condition with respect to p yields

$$\begin{aligned}
&-\bar{R}\mathbb{E}[u'(\bar{R}w^U + (\tilde{\theta} - p\bar{R})x) \mid z] \\
&+ \bar{R}(\omega - x)\mathbb{E}[u''(\bar{R}w^U + (\tilde{\theta} - p\bar{R})x)(\tilde{\theta} - p\bar{R}) \mid z] \\
&+ \mathbb{E}[u''(\bar{R}w^U + (\tilde{\theta} - p\bar{R})x)(\tilde{\theta} - p\bar{R})^2 \mid z]\frac{\partial x}{\partial p} = 0,
\end{aligned} \tag{14}$$

where $w^U = \omega p + (1 - \omega)$. The first two terms can be combined to

$$\begin{aligned}
-\bar{R}\mathbb{E}[u'(\bar{R}w^U + (\tilde{\theta} - p\bar{R})x)(1 - \mathcal{R}(\bar{R}w^U + (\tilde{\theta} - p\bar{R})x) \\
+ \mathcal{A}(\bar{R}w^U + (\tilde{\theta} - p\bar{R})x)(\omega\tilde{\theta} + (1 - \omega)\bar{R}))].
\end{aligned} \tag{15}$$

Consider the term $\omega\tilde{\theta} + (1 - \omega)\bar{R}$. Note that for it to be equal to 0 it must be the case that $\omega = 1$ and $\tilde{\theta} = 0$ as $\theta_s \geq 0$ for all s. However, in this case an uninformed trader's problem would only have a solution if $p = 0$, implying that $\omega = 0$. Therefore, the expectation of the term involving $\omega\tilde{\theta} + (1 - \omega)\bar{R}$) is strictly positive. Consequently, (15) is strictly negative when $\mathcal{R}(\cdot) \leq 1$. Thus, $\partial x/\partial p < 0$ if the coefficient of relative risk aversion is less or equal than one. □

Intuitively, given that traders' coefficient of relative risk aversion is less than 1, the wealth effect of a higher p is moderate enough to ensure that uninformed traders' demand for the risky asset is decreasing in p. Taken together, Lemmas 3 and 4 characterise the aggregate demand for the risky asset for all $p \neq 1$. However, due to $p = 1$ being partially-revealing, the aggregate demand can exhibit a discontinuity at $p = 1$. Nevertheless, the existence of equilibrium can be proven.

Proposition 1. *Rational expectations equilibrium exists.*

Proof. Denote the aggregate demand for the risky asset when all traders know the realisation signal with $x^A(p, z)$. Clearly, for $p \neq 1$, $x^A(p, z) = \lambda x^I(p, z) + x^U(p)$. Note from traders' first-order conditions that $x^A(0) \geq 0$ as $\theta_s \geq 0$ for all s. Similarly, for p sufficiently high and above unity, $x^A(p, z) < 0$ as $\theta_s - p\bar{R} < 0$ for all s. Moreover, by Lemmas 3 and 4, $x^A(p, z)$ is continuously decreasing in p. Consequently, if $x^A(1, z) > 1$, there exists $p > 1$ such that $x^A(p, z) = 1$. Similarly, if $x^A(1, z) < 0$, there exists $p < 1$ such that $x^A(p, z) = 0$.

Consider any realisation of the signal z. Note that when the equilibrium price reveals the signal realisation, aggregate demand for the risky asset is given by $x^A(p, z)$. To find an equilibrium price for the signal realisation z, consider $x^A(1, z)$. If $x^A(1, z) > 1$, there exists an equilibrium price $p > 1$ for the signal realisation z by the argument above. Similarly, if $x^A(1, z) < 0$, there exists an equilibrium price $p < 1$.

What remains is to consider signal realisations for which $x^A(1, z) \in [0, 1]$. Consider an equilibrium in which $p \neq 1$ whenever $x^A(1, z) \notin [0, 1]$. Then, $p = 1$ reveals that $x^A(1, z) \in [0, 1]$. Let me show that this implies that $\lambda x^I(1, z) + x^U(1) \in [0, 1]$. Suppose otherwise. There are two cases to consider. First, suppose that $x^U(1) > 1 - \lambda x^I(1, z) =: h(z)$. Then,

$$\begin{aligned} &\mathbb{E}[u'(\bar{R}w^U + (\tilde{\theta} - p\bar{R})h(z))(\tilde{\theta} - p\bar{R}) \mid p = 1] \\ =&\mathbb{E}[u'(\bar{R}w^U + (\tilde{\theta} - p\bar{R})h(z))(\tilde{\theta} - p\bar{R}) \mid z \in \mathcal{Z}^U] > 0, \end{aligned} \tag{16}$$

where $\mathcal{Z}^U = \{z \mid x^A(1, z) \in [0, 1]\}$ and $w^U = \omega p + (1 - \omega)$. However, note that

$$\mathbb{E}[u'(\bar{R}w^U + (\tilde{\theta} - p\bar{R})h(z))(\tilde{\theta} - p\bar{R}) \mid z] < 0 \tag{17}$$

for all $z \in Z^U$. Then, by the law of iterated expectations

$$\mathbb{E}[u'(\bar{R}w^U + (\tilde{\theta} - p\bar{R})h(z))(\tilde{\theta} - p\bar{R}) \mid z \in \mathcal{Z}^U] < 0, \tag{18}$$

constituting a contradiction. The second case of $x^U(1) < -\lambda x^I(1, z)$ can be shown to lead to a contradiction following the same steps. Hence, if $x^A(1, z) \in$

$[0, 1]$, then $\lambda x^I(1, z) + x^U(1) \in [0, 1]$. Therefore, there exists an equilibrium in which $p = 1$ whenever $x^A(1, z) \in [0, 1]$. $\square$

Proposition 1 provides a straightforward way to construct an equilibrium price functional. Namely, for each signal realisation z, one evaluates the aggregate demand for the risky asset when all traders know the realisation of the signal $x^A(p, z)$ at $p = 1$. If $x^A(1, z) \in [0, 1]$, $p = 1$ constitutes an equilibrium price for z. Otherwise, the equilibrium price can be solved for from $x^A(p, z) = \omega(p)$. Notably, one does not need to solve explicitly for the equilibrium belief of the uninformed traders when the equilibrium price is partially-revealing.

What remains is to define a measure of the informativeness of equilibrium prices. Given that $p = 1$ reveals that the signal is not in the set for which a fully-revealing price obtains, a natural measure of informativeness is the probability of observing a fully-revealing price. Note that this measure takes into consideration that when a perfectly-revealing price obtains for fewer signals, the partially-revealing price is a more imprecise signal about the return of the risky asset.

Definition 2. *The informativeness of the stock price is* $\mathbb{P}(\mathcal{P}(z) \neq 1)$.

4 Informativeness of the stock price

In this section, I address the question of how the informativeness of the stock price varies with the parameters of the model. Given that a fully-revealing equilibrium price requires aggregate demand for the risky asset to be either sufficiently low or sufficiently high, the information content of the stock price depends crucially on the traders' positions in the risky asset. For this reason, I will first study what determines the sign of traders' positions in the risky asset and how traders' demands responds to changes in the parameters of the model. The results are summarised in the following lemmas. Even though the proofs are standard (see, e.g., LeRoy and Werner, 2001), they are given for completeness.

Lemma 5. *For* $J \in \{I, U\}$, $x^J > 0$ *when* $\mathbb{E}[\tilde{\theta} \,|\, \mathcal{I}^J] - p\bar{R} > 0$, $x^J < 0$ *when* $\mathbb{E}[\tilde{\theta} \,|\, \mathcal{I}^J] - p\bar{R} < 0$ *and* $x^J = 0$ *when* $\mathbb{E}[\tilde{\theta} \,|\, \mathcal{I}^J] - p\bar{R} = 0$.

Proof. The objective of a trader of either type is concave in their investment in the risky asset as by the strict concavity of $u(\cdot)$

$$\frac{\partial^2}{\partial x^2}\mathbb{E}[u(\bar{R}w^J + (\tilde{\theta} - p\bar{R})x) \,|\, \mathcal{I}^J] = \mathbb{E}[u''(\bar{R}w^J + (\tilde{\theta} - p\bar{R})x)(\tilde{\theta} - p\bar{R})^2 \,|\, \mathcal{I}^J] < 0, \tag{19}$$

where $J \in \{I, U\}$, $w^I = w$ and $w^U = \omega p + (1 - \omega)$. A trader's first-order condition evaluated at $x = 0$ is

$$\mathbb{E}[u'(\bar{R}w^J)(\tilde{\theta} - p\bar{R}) \,|\, \mathcal{I}^J] = u'(\bar{R}w^J)(\mathbb{E}[\tilde{\theta}, \,|\, \mathcal{I}^J] - p\bar{R}). \tag{20}$$

The equality follows from the fact that conditional on the equilibrium price, w^J is nonstochastic also for an uninformed trader (equal to 1 for $p \leq 1$ and p for $p > 1$). Given that $u(\cdot) > 0$ and the objective is strictly concave, the sign of $\mathbb{E}[\tilde{\theta} \,|\, \mathcal{I}^J] - p\bar{R}$ determines whether $x^J < 0$, $x^J = 0$ or $x^J > 0$ as stated in the lemma. □

Lemma 6. *For u exhibiting decreasing absolute risk aversion, $\partial x^I/\partial w > 0$ when $\mathbb{E}[\tilde{\theta} \,|\, z] - p\bar{R} > 0$, $\partial x^I/\partial w < 0$ when $\mathbb{E}[\tilde{\theta} \,|\, z] - p\bar{R} < 0$ and $\partial x^I/\partial w = 0$ when $\mathbb{E}[\tilde{\theta} \,|\, z] - p\bar{R} = 0$.*

Proof. Differentiating the informed traders' first-order condition with respect to w gives

$$\begin{aligned} &\bar{R}\mathbb{E}[u''(\bar{R}w + (\tilde{\theta} - p\bar{R})x)(\tilde{\theta} - p\bar{R}) \,|\, z] \\ &+ \mathbb{E}[u''(\bar{R}w + (\tilde{\theta} - p\bar{R})x)(\tilde{\theta} - p\bar{R})^2 \,|\, z]\frac{\partial x}{\partial w} = 0 \end{aligned} \tag{21}$$

Given that the term multiplying $\partial x/\partial w$ is strictly negative, the sign of the derivative is determined by the first term in (21). Note that

$$\frac{u''(\bar{R}w + (\theta_s - p\bar{R})x)(\theta_s - p\bar{R})}{u'(\bar{R}w + (\theta_s - p\bar{R})x)} = -\mathcal{A}(\bar{R}w + (\theta_s - p\bar{R})x)(\theta_s - p\bar{R}). \tag{22}$$

As $\mathcal{A}$ is decreasing, one obtains for $x > 0$ and all s

$$\mathcal{A}(\bar{R}w + (\theta_s - p\bar{R})x)(\theta_s - p\bar{R}) \leq \mathcal{A}(\bar{R}w)(\theta_s - p\bar{R}), \tag{23}$$

with the inequality strict for at least one s. This implies that

$$-u''(\bar{R}w + (\theta_s - p\bar{R})x)(\theta_s - p\bar{R}) \geq -\mathcal{A}(\bar{R}w)(\theta_s - p\bar{R})u'(\bar{R}w + (\theta_s - p\bar{R})x), \tag{24}$$

where the expected value of the right-hand side is 0 by (6). Thus,

$$\bar{R}\mathbb{E}[u''(\bar{R}w + (\tilde{\theta} - p\bar{R})x)(\tilde{\theta} - p\bar{R}) \,|\, z] > 0, \tag{25}$$

proving that $\partial x/\partial w > 0$. For $x < 0$, the inequality (23) is reversed, yielding $\partial x/\partial w < 0$. Similarly, for $x = 0$, (23) becomes an equality, allowing one to conclude that $\partial x/\partial w = 0$. By Lemma (5), $x < 0$, $x = 0$ and $x > 0$ when $\mathbb{E}[\tilde{\theta} \,|\, z] - p\bar{R} < 0$, $\mathbb{E}[\tilde{\theta} \,|\, z] - p\bar{R} = 0$ and $\mathbb{E}[\tilde{\theta} \,|\, z] - p\bar{R} > 0$, respectively. □

When the informed traders' utility function exhibits decreasing risk aversion they take a larger position, of either sign, in the risky asset when their wealth increases. The reason for this is that decreasing risk aversion renders the risky asset a normal good. Note that if traders' coefficient of relative risk aversion is constant or decreasing, then u exhibits decreasing absolute risk aversion. Hence, u can simultaneously exhibit decreasing absolute risk aversion and have a coefficient of relative risk aversion less or equal than unity, the assumption maintained throughout.

Lemma 7. *For $J \in \{I, U\}$, $\partial x^J/\partial \bar{R} < 0$.*

Proof. Differentiating a trader's first-order condition with respect to $\bar{R}$ yields

$$
\begin{aligned}
&- p\mathbb{E}[u'(\bar{R}w^J + (\tilde{\theta} - p\bar{R})x) \,|\, \mathcal{I}^J] - (w^J - px)\mathbb{E}[u''(\bar{R}w^J + (\tilde{\theta} - p\bar{R})x)(\tilde{\theta} - p\bar{R}) \,|\, \mathcal{I}^J] \\
&+ \mathbb{E}[u''(\bar{R}w^J + (\tilde{\theta} - p\bar{R})x)(\tilde{\theta} - p\bar{R})^2 \,|\, \mathcal{I}^J]\frac{\partial x}{\partial \bar{R}} = 0.
\end{aligned} \tag{26}
$$

As the term multiplying $\partial x/\partial \bar{R}$ is negative, the sign of the derivative is determined by the first two terms. Rearranging these two terms gives

$$
- p\mathbb{E}[u^{J\prime}(c^J)[1 - \mathcal{R}(c^J) + \mathcal{A}(c^J)\tilde{\theta}\frac{w^J}{p}] \,|\, \mathcal{I}^J] < 0, \tag{27}
$$

where $c^J = \bar{R}w^J + (\tilde{\theta} - p\bar{R})x$ and the inequality follows from the fact that $\mathcal{R}(\cdot) \leq 1$. Thus, $\partial x^J/\partial \bar{R} < 0$. □

Given that traders' preferences are characterised by a coefficient of relative risk aversion less or equal than unity, the income effect of a change in the risk-free rate is moderate. This ensures that traders' positions in the risky asset decrease with the risk-free rate.

To derive implications of shifts in traders' demands for the informativeness of the stock price, a stance has to be taken on how to deal with potential multiplicity of equilibria. Consider the equilibrium price for the signal z before and after varying a parameter of the model. If either before or after the change the equilibrium price for z is not unique but the equilibrium prices for z across the two economies are informationally equivalent, the equilibria will be said to belong to the same class.

Definition 3. *The equilibria of the economies $\mathcal{E}$ and $\mathcal{E}'$ belong to the same class if for all z for which the equilibrium price is not unique in either $\mathcal{E}$ or $\mathcal{E}'$, either $\mathcal{P}(z) = \mathcal{P}'(z) = 1$ or $\mathcal{P}(z) \neq 1$ and $\mathcal{P}'(z) \neq 1$, where $\mathcal{P}$ and $\mathcal{P}'$ denote the equilibrium price functionals in the economies $\mathcal{E}$ and $\mathcal{E}'$, respectively.*

It should be pointed out considering equilibria belonging to the same class allows for considerable flexibility in resolving potential equilibrium multiplicity. For instance, always choosing the most informative equilibrium, i.e. the equilibrium in which an perfectly-revealing price obtains for the largest measure of signals, ensures that equilibria across models belong to the same class.[4] Similarly, always choosing the least informative equilibrium delivers equilibria in the same class. Equipped with Lemmas 6 and 7, I can turn to the informativeness of the stock price. Let me begin by investigating the effect of an increase in the wealth of the informed traders.

Proposition 2. *If traders' preferences are characterised by decreasing absolute risk aversion, the informativeness of the stock price is increasing in the wealth of the informed traders across equilibria belonging to the same class.*

Proof. Given that $p < 1$ fully reveals z, $\mathbb{E}[\tilde{\theta} \mid z] = \mathbb{E}[\tilde{\theta} \mid p]$. Since $\omega(p) = 0$ for $p < 1$, market-clearing and Lemma 5 imply that $\mathbb{E}[\tilde{\theta} \mid z] = p\bar{R}$. Hence, each trader takes a 0 position in the risky asset. Moreover, by Lemma 6, $\partial x^I / \partial w = 0$ in this case. Hence, an increase in w leaves all equilibrium prices $p < 1$ unaffected. Similarly, for $p > 1$, $\mathbb{E}[\tilde{\theta} \mid z] = \mathbb{E}[\tilde{\theta} \mid p] > p\bar{R}$, where the inequality follows from market clearing and Lemma 5. Thus, in this case, $\partial x^I / \partial w > 0$ by Lemma 6. Hence, an increase in w leads to a higher equilibrium prices but leaves the informativeness of the price unaffected. Therefore, no fully-revealing equilibrium price becomes partially-revealing upon an increase in the wealth of the informed traders. Thus, the set of signals for which a fully-revealing price obtains increases in measure, at least weakly, on an increase in w. □

When informed traders are endowed with a larger endowment, they take larger positions, of either sign, in the risky asset. This implies that the aggregate demand for the risky asset is more likely to fall outside the range of partially-revealing equilibrium prices. Consequently, the stock price becomes more informative. Note that the effect of informed traders' wealth, albeit intuitive, requires an additional restriction on traders' preferences. However, if the two groups of traders differed in their preferences, only informed traders' preferences would need to exhibit decreasing absolute risk aversion for Proposition 2 to obtain.

Let me next investigate a change in the risk-free rate $\bar{R}$. By Lemma 7, a decrease in the risk-free rate leads to an increase in the informed traders' demand for the risky asset. Consequently, the following obtains.

[4] The algorithm used to prove the existence of equilibrium (Proposition 1) yields the most informative equilibrium.

Proposition 3. *If the supply of the risky asset is always strictly positive, the informativeness of the stock price is decreasing in the risk-free rate across equilibria belonging to the same class.*

Proof. Given that the supply of the risky asset is always strictly positive, all fully-revealing prices satisfy $p > 1$. From Lemma 7, the aggregate demand for the risky asset is decreasing in the risk-free rate. Thus, for z such that $p > 1$, an increase in $\bar{R}$ leads to a lower equilibrium price. If the equilibrium price falls to 1, the signal z no longer supports a fully-revealing price. Thus, an increase in the risk-free rate lowers, at least weakly, the probability of $\mathbb{P}(p \neq 1)$. □

Note that the condition that the supply of the risky asset is always strictly positive is relatively weak. It merely requires the expected excess return of the risky asset to be such that traders on aggregate have a long position in equity. The decrease in the informativeness of the stock price on an increase in the risk-free rate derives from the fall in the aggregate demand for the risky asset, lowering the probability of fully-revealing prices.

5 Welfare

Given the absence of noise traders, the environment allows for analysing traders' welfares when varying the intensity of informed trading. However, before doing so, it is natural to equalise the endowments of the two groups of traders and fix the total measure of traders. This ensures that changing the measure of informed traders does not alter the aggregate resource constraint of the economy. Hence, in this section, the total measure of traders is normalised to 1, fraction λ of which are informed traders. Each trader is endowed with 1 share of the representative firm. These alterations do not invalidate Proposition 1, the existence of rational expectations equilibrium. This can be seen by applying Lemma 4 to informed traders, implying that x^I is strictly decreasing in the relative price of the risky asset p. Therefore, aggregate demand for the risky asset $\lambda x^I(p, z) + (1 - \lambda)x^U(p)$ is still strictly decreasing in p for all $p \neq 1$.

Let me address the question of how traders' welfares respond to an increase in the fraction of informed traders. Notably, the following obtains.

Proposition 4. *There exists an equilibrium price functional which is invariant to the fraction of informed firms.*

Proof. Consider the algorithm used to show the existence of equilibrium in the proof of Proposition 1. When all traders know the realisation of the signal, aggregate demand for the risky asset is given by $x^I(p, z)$, a term independent of λ. Hence, whether for a given signal realisation a fully-revealing or a partially-revealing equilibrium price obtains is independent of λ. □

The fraction of informed firms does not affect price informativeness due to the endogenous nature of noise in equilibrium prices. Namely, when there are more informed traders, the supply of risky assets responds more strongly to the price pressure exerted by informed traders. As to traders' welfares, Proposition 4 directly implies the following.

Corollary 1. *There exists a class of equilibria within which the expected utility of a trader of either type is invariant to the fraction of informed firms.*

Proof. Note that a trader's initial wealth $\omega p + (1 - \omega)$ is nonstochastic given p. Therefore, their demand for the risky asset and their date-1 consumption are determined by the equilibrium price. Hence, trader's expected utilities are determined by the equilibrium price functional. Hence, within a class of equilibria with an invariant equilibrium price functional, the existence of which is guaranteed by Proposition 4, traders' welfares are invariant to the fraction of informed firms. □

In sum, the welfare analysis shows that the number of informed traders does not necessarily determine the informativeness of stock prices and traders' welfares. Rather the information content of equilibrium prices hinges on market conditions such as the level of the risk-free rate. This finding relies on the endogeneity of noise in equilibrium prices and for this reason cannot obtain in Grossman-Stiglitz-type models where noise arises from exogenous noise trading.

6 Empirics

Confronting the predictions of the theoretical model with data presents two challenges. First, one should find a reliable proxy for the fundamental value of a stock. Second, in order to exploit time variation in market conditions, the dynamic implications of the model should be investigated. To overcome these challenges, an indirect approach to testing the theoretical implications is adopted. Namely, serial correlation in total stock returns is used as a measure of the informativeness of stock prices.[5] The idea is that stock returns are

[5] An alternative would be to use the probability of informed trading (see Easley et al., 1996) to measure the informativeness of the stock price. However, given that this measure is based on a market microstructure model of informed trading à la Kyle (1985) whereas

serially correlated if information gets incorporated into prices only gradually. Thus, serial correlation in stock returns should decrease as prices become more informative. Then, it is investigated how serial correlation varies with the market conditions identified by the theory as determinants of the informativeness of stock prices. However, due to the indirect nature of the empirical approach, the results below should be seen merely as suggestive evidence for the mechanisms of the theoretical model. Before turning to the empirical analysis, I will explain how partially-revealing prices can lead to serial correlation in returns.

6.1 Serial correlation in stock returns

Consider a dynamic extension of the model presented in Section 2. Namely, the economy is infinitely-lived. The risky asset pays a dividend of $\tilde{\theta}_t$ in period t. The traders still have access to the risk-free asset, yielding a one-period gross return of $\bar{R}$. In each period, the representative firm chooses the amount of risky assets in the economy as in the one-period model, carrying out a debt-for-equity or equity-for-debt swaps. Hence, the amount of risky assets in the economy is bounded between 0 and 1 in each period. Informed traders receive an informative signal about the flow of future dividends whereas uninformed traders' information set contains the past dividend flows and the current price of the risky asset. The one-period return of the risky asset is given by $(\theta_{t+1} + p_{t+1})/p_t$. Consider a case in which the price of the risky asset is unresponsive to information about future dividends. Then, any serial correlation in dividends leads to serial correlation in returns. On the other hand, when future dividends are known by all traders, the return of the risky asset is equal to $\bar{R}$, exhibiting no serial correlation.

6.2 Data

The risky asset in the model can be seen as a market portfolio. For this reason, the empirical analysis concerns an index of stocks. More specifically, value-weighted daily returns of all Center for Research in Security Prices (CRSP) firms incorporated in the US and listed on the NYSE, AMEX or NASDAQ are analysed. Given that serial correlation in an index return can arise from nonsynchronous trading (Scholes and Williams, 1977), one might wish to investigate individual stock returns instead. However, Lo and MacKinlay (1988) show that the serial correlation arising from plausible levels of nonsynchronous trading is

the present study pertains to informed trading in a Walrasian market, this would be less appropriate.

very small. For this reason, index of stocks, the empirical counterpart of the risky asset in the model, is investigated.

As to the risk-free rate, the secondary market rate of the 3-month Treasury bill, provided by the Federal Reserve Board, is employed. Even though a shorter maturity might be preferable due to the analysis pertaining to daily returns, the 3-month bill is chosen as it is available for a longer time period than other daily bond series. Both the stock return and the Treasury bill data span the period 04/01/1954–30/04/2014.

Measuring the wealth of the investors is less straightforward. Direct measures are practically ruled out by the requirement that the data be available at a daily frequency. Hence, I will instead use a proxy for funding liquidity, capturing investors' ability to take positions in different assets (Brunnermeier and Pedersen, 2009). Following a growing literature (e.g. Gatev and Strahan, 2006 and Hameed, Kang, and Viswanathan, 2010), I use the spread between the returns of commercial paper (CP) and Treasury bills (paper-bill spread) as a proxy for funding liquidity. Commercial paper is essentially a completely illiquid security (Krishnamurthy, 2002). Moreover, commercial papers has minimal credit risk (Kacperczyk and Schnabl, 2010). For these reasons, the paper-bill spread mainly reflects liquidity premium demanded by CP investors. In other words, the paper-bill spread measures changes in supply of funding liquidity.

To compute the paper-bill spread, I use the 3-month financial commercial paper rate[6] and Treasury bill rate described above. Financial commercial paper is used to raise funds by large financial institutions (Kacperczyk and Schnabl, 2010), hence being suitable for measuring the funding liquidity of financial market participants.

6.3 Results

I will begin by investigating the individual effect of the Treasury bill rate on the serial correlation of returns. As the informativeness of stock prices is predicted to be decreasing in the risk-free rate, serial correlation should increase with the Treasury bill rate. That is, in the following empirical specification

$$R_t = \alpha + \beta R_{t-1} + \gamma R_{t-1} TB_{t-1} + \epsilon_t, \tag{28}$$

the coefficient γ is expected to be positive. Note however that the Treasury bill rate can have on effect on the serial correlation both as it proxies for the

[6] I employ the 3-month finance paper rate for the period 05/05/1954–31/12/1996 and the 90-day AA financial commercial paper for 02/01/1997–30/04/2014, both provided by the Federal Reserve Board.

risk-free rate and as it captures movements in funding liquidity. In particular, if a higher Treasury bill rate is associated with abundant funding liquidity, the estimate of γ is likely to be biased downward.

Due to the fact the Treasury bill rate is not stationary, it has to be transformed before estimating (28). To do so, I deduct a 60-day backward moving average from the Treasury bill rate to obtain what Campbell (1991) calls the relative interest rate. The idea is that the transformed variable measures innovations to the risk-free rate. Later I show that the results are robust to alternative ways of stationarising the Treasury bill rate.

Table 1 presents the results of estimating the effect of the Treasury bill rate. As shown by the first specification, daily index returns are significantly serially correlated. This finding might at first sight be surprising, indicating predictability of stock returns. However, serial correlation of daily returns has been robustly established in the literature (see, e.g., Campbell, Grossman, and Wang, 1993). Among the proposed explanations of serial correlation perhaps the most prominent is nonsynchronous trading. The idea is that if not all stocks are traded at all times, information about future returns becomes incorporated into prices only gradually. However, even though nonsynchronous trading can explain why stock returns can be serially correlated, it is not clear why the the degree of nonsynchronous trading would vary with Treasury bill rate and the paper-bill spread.

The second specification in Table 1 shows that serial correlation in stock returns rises when the Treasury bill rate is above its past average value. Finally, the third specification shows that the result is robust to adding interaction terms of the lagged return and day of the week dummies. Each of these interaction terms is statistically significant at the 5% level. Thus, the results provide suggestive evidence for the model's prediction that stock prices are less informative when the level of the risk-free rate is high.

Turning to the effect of the paper-bill spread, I first analyse the individual effect of the spread on the serial correlation of returns. Given that a higher spread indicates scarcity of funding liquidity, the coefficient on δ in the following specification is expected to be positive

$$R_t = \alpha + \beta R_{t-1} + \delta R_{t-1}(CP_{t-1} - TB_{t-1}) + \epsilon_t. \tag{29}$$

Note that if δ merely captures the effect of the risk-free rate on the serial correlation, it should have a negative sign. Hence, in specification (29), the estimate of δ is likely to be biased downward. Finally, I estimate a specification with both the paper-bill spread and the Treasury bill rate.

The results on the effect of the paper-bill spread are less clear-cut than those on the Treasury bill rate. Namely, when estimating specification (29)

	Dependent variable: R_t		
Explanatory variable	(1)	(2)	(3)
R_{t-1}	0.0615***	0.0672***	0.255***
	(0.0160)	(0.0138)	(0.0532)
$R_{t-1}TB_{t-1}$		0.0541*	0.0568*
		(0.0273)	(0.0279)
$R_{t-1}\times$ day of the week			✓
R^2	0.00378	0.00485	0.0153
observations	15186	15018	15018

Table 1: Full sample. Newey-West standard errors in parentheses. ***, ** and * denote significance at the 0.1%, 1% and 5% level, respectively.

using the full sample, $\hat{\delta}$ is positive but not statistically significant. But when employing the second half of the sample, a statistically significant estimate for δ obtains. These results are reported in Table 2.

As expected, the paper-bill spread has a larger effect in specification (1) than in specification (2), where the Treasury bill rate is included separately. Notably, the coefficients of both the paper-bill spread and the Treasury bill rate are positive and significant in the second specification, as suggested by the theoretical model. The third specification shows that the findings are robust to interacting the lagged return with day of the week dummies. In sum, the results suggest that the serial correlation in stock returns is increasing in both the risk-free rate and funding illiquidity.

6.4 Alternative interest rate measures

Let me address the robustness of the results to alternative ways of stationarising the Treasury bill and the commercial paper rates. I conduct two experiments. First, I will vary the length of the window over which the backward moving average of the rates are calculated. Second, instead of considering deviations from a moving average, I will use first differences of the rates to capture innovations to these variables.

Table 3 shows the effect of varying the number of days over which the moving average of the TB and CP rates are computed. For comparability with the previous findings, the second half of the sample is employed. One observes that results are little affected by these alterations.

Table (4), presents the estimates when first differences of the rates are

	Dependent variable: R_t		
Explanatory variable	(1)	(2)	(3)
R_{t-1}	-0.0111	0.00679	0.171*
	(0.0279)	(0.0206)	(0.0829)
$R_{t-1}(CP_{t-1} - TB_{t-1})$	0.0559**	0.103***	0.126**
	(0.0203)	(0.0292)	(0.0475)
$R_{t-1}TB_{t-1}$		0.160*	0.170*
		(0.0771)	(0.0838)
$R_{t-1}\times$ day of the week			✓
R^2	0.000725	0.00365	0.0128
observations	7416	7416	7416

Table 2: Second half of the sample. Newey-West standard errors in parentheses. ***, ** and * denote significance at the 0.1%, 1% and 5% level.

	Dependent variable: R_t		
Explanatory variable	(1)	(2)	(3)
R_{t-1}	0.171*	0.170*	0.171*
	(0.0829)	(0.0834)	(0.0830)
$R_{t-1}(CP_{t-1} - TB_{t-1})$	0.126**	0.144*	0.110**
	(0.0475)	(0.0579)	(0.0421)
$R_{t-1}TB_{t-1}$	0.170*	0.192*	0.145*
	(0.0838)	(0.0963)	(0.0735)
$R_{t-1}\times$ day of the week	✓	✓	✓
R^2	0.0128	0.0125	0.0126
observations	7416	7416	7416

(1): TB and CP deviations from 60-day backward moving averages.
(2): TB and CP deviations from 40-day backward moving averages.
(3): TB and CP deviations from 80-day backward moving averages.

Table 3: Second half of the sample. Newey-West standard errors in parentheses. ***, ** and * denote significance at the 0.1%, 1% and 5% level.

	Dependent variable
Explanatory variable	R_t
R_{t-1}	0.240***
	(0.0567)
$R_{t-1}(\Delta CP_{t-1} - \Delta TB_{t-1})$	0.208*
	(0.0973)
$R_{t-1}\Delta TB_{t-1}$	0.255*
	(0.103)
$R_{t-1}\times$ day of the week	✓
R^2	0.0168
observations	14651

Table 4: Full sample. Newey-West standard errors in parentheses. ***, ** and * denote significance at the 0.1%, 1% and 5% level.

used. The specification is estimated over the full sample. Also in this case, both the paper-bill spread and the Treasury bill rate have positive and statistically significant coefficients, lending further support to serial correlation of stock returns being increasing in the risk-free rate and funding illiquidity.

7 Conclusion

This paper develops a novel framework for analysing the information content of asset prices under asymmetric information. Notably, only mild restrictions are imposed on traders' preferences and the distribution of payoffs. Moreover, the model features endogenous asset supply, which introduces noise to the information revealed by equilibrium prices and obviates the need for noise trading. The framework is used to analyse the determinants of stock price informativeness. It is found that the informativeness of stock prices is increasing in the wealth of informed traders and decreasing in the risk-free rate. This is due to the fact that when informed traders take larger positions, stock prices move more strongly with the information possessed by these traders. Notably, the information content of equilibrium prices and traders' welfares can be invariant to the intensity of informed trading. US stock market data provides suggestive evidence for the mechanisms identified by the theoretical analysis. Namely, serial correlation in stock returns, a proxy for the degree to which prices fail to incorporate new information, is found to be increasing in the risk-free rate and in funding illiquidity.

References

Aumann, Robert J. 1976. "Agreeing to Disagree." *Annals of Statistics* 4 (6):1236–1239.

Ausubel, Lawrence M. 1990. "Partially-revealing rational expectations equilibrium in a competitive economy." *Journal of Economic Theory* 50 (1):93–126.

Ball, Ray. 1978. "Anomalies in relationships between securities' yields and yield-surrogates." *Journal of Financial Economics* 6 (2–3):103–126.

Brunnermeier, Markus K. and Lasse Heje Pedersen. 2009. "Market Liquidity and Funding Liquidity." *Review of Financial Studies* 22 (6):2201–2238.

Campbell, John Y. 1991. "A Variance Decomposition for Stock Returns." *Economic Journal* 101 (405):157–179.

Campbell, John Y., Sanford J. Grossman, and Jiang Wang. 1993. "Trading Volume and Serial Correlation in Stock Returns." *Quarterly Journal of Economics* 108 (4):905–939.

Chen, Qi, Itay Goldstein, and Wei Jiang. 2007. "Price Informativeness and Investment Sensitivity to Stock Price." *Review of Financial Studies* 20 (3):619–650.

Dow, James and Rohit Rahi. 2003. "Informed Trading, Investment, and Welfare." *Journal of Business* 76 (3):439–454.

Easley, David, Nicholas M. Kiefer, Maureen O'Hara, and Joseph B. Paperman. 1996. "Liquidity, Information, and Infrequently Traded Stocks." *Journal of Finance* 51 (4):1405–1436.

Fama, Eugene F. 1998. "Market efficiency, long-term returns, and behavioral finance." *Journal of Financial Economics* 49 (3):283–306.

Fishburn, Peter C. and R. Burr Porter. 1976. "Optimal Portfolios with One Safe and One Risky Asset: Effects of Changes in Rate of Return and Risk." *Management Science* 22 (10):1064–1073.

Gatev, Evan and Philip E. Strahan. 2006. "Banks' Advantage in Hedging Liquidity Risk: Theory and Evidence from the Commercial Paper Market." *Journal of Finance* 61 (2):867–892.

Grossman, Sanford J. and Joseph E. Stiglitz. 1976. "Information and Competitive Price Systems." *American Economic Review* 66 (2):246–253.

———. 1980. "On the Impossibility of Informationally Efficient Markets." *American Economic Review* 70 (3):393–408.

Hameed, Allaudeen, Wenjin Kang, and S. Viswanathan. 2010. "Stock Market Declines and Liquidity." *Journal of Finance* 65 (1):257–293.

Kacperczyk, Marcin and Philipp Schnabl. 2010. "When Safe Proved Risky: Commercial Paper during the Financial Crisis of 2007–2009." *Journal of Economic Perspectives* 24 (1):29–50.

Krishnamurthy, Arvind. 2002. "The bond/old-bond spread." *Journal of Financial Economics* 66 (2–3):463–506.

Kyle, Albert S. 1985. "Continuous Auctions and Insider Trading." *Econometrica* 53 (6):1315–1335.

LeRoy, Stephen F. and Jan Werner. 2001. *Principles of Financial Economics*. Cambridge, UK: Cambridge University Press.

Lo, Andrew W. and A. Craig MacKinlay. 1988. "Stock market prices do not follow random walks: evidence from a simple specification test." *Review of Financial Studies* 1 (1):41–66.

Polk, Christopher and Paola Sapienza. 2009. "The Stock Market and Corporate Investment: A Test of Catering Theory." *Review of Financial Studies* 22 (1):187–217.

Scholes, Myron and Joseph Williams. 1977. "Estimating betas from nonsynchronous data." *Journal of Financial Economics* 5 (3):309–327.

Wang, Jiang. 1994. "A Model of Competitive Stock Trading Volume." *Journal of Political Economy* 102 (1):127–168.