Learning from Interest Rates: Implications for Stock-Market Efficiency*

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Abstract

We propose a novel theory and supporting empirical evidence that lowering interest rates (e.g., as a result of quantitative easing) harms the informational and allocative efficiency of the stock market. In our noisy rational expectations equilibrium model, the endogenously-determined interest rate contains information about the discount rate, which helps investors interpret the information about cashflows capitalized into stock prices. The strength of this mechanism and, hence price informativeness, are increasing in the interest rate. We discuss the impact of monetary and fiscal policies on informational and real efficiency, and other properties of the stock market (e.g., the price of risk).

Keywords: (endogenous) interest rates, rational expectations, informational efficiency, capital-allocation efficiency, fiscal and monetary policy

JEL: E43, E44, G11, G14

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Interest rates play an essential role in financial markets. Foremost, they represent the rate at which investors discount risk-free as well as risky future cash flows. But together with other assets' prices, they also convey valuable information about the economic outlook.[1] In recent years, however, market participants have expressed concerns that unconventional monetary policy (i.e., quantitative easing) has distorted rates, and with them other assets' prices, to the point that the prices of many assets have lost their predictive power.[2]

The purpose of this paper is to investigate such claims, and to provide novel empirical and theoretical insights into the link between interest rates and the informativeness of prices. We start with an examination of the data, focusing on the stock market. We find that stock price informativeness (measured as in Bai, Philippon, and Savov 2016) is strongly positively correlated with interest rates—see Panel A of Figure 1 for an illustration. Consistent with this relation, it correlates positively with proxies for the supply of Treasury bonds, and negatively with proxies for the demand for bonds (which serve as instruments for the endogenous interest rate). The data also indicate a degradation of price informativeness since 2008, thus lending support to the claims that quantitative easing (QE, henceforth) has reduced the discriminatory power of stock prices.

The remainder of our paper is dedicated to understanding the theoretical underpinnings of such a phenomenon. Specifically, we study how investors extract information from interest rates to learn about economic fundamentals. Our analysis sheds light on how bond-market characteristics (e.g., the supply of bonds) impact informational efficiency—the ability of financial markets to aggregate and disseminate private information—as well as real efficiency—their ability to allocate capital. More generally, by accounting for informational side-effects, it improves our understanding of the impact of government (central bank) policies on economic outcomes.

[1] The literature on the informational content of asset prices is extensive. For evidence on the predictive power of the term structure, see, for example, Harvey (1988), Mishkin (1990), Estrella and Mishkin (1998), and Ang, Piazzesi, and Wei (2006).

[2] For example, in July 2018, the former chairman of the Federal Reserve, Ben Bernanke, warned that, because of "distortions" in financial markets, a yield-curve inversion might not necessarily point to a recession. Moreover, worries that low interest rates might distort stock prices and lead to a misallocation of capital have been frequently voiced; for instance by Mario Draghi, then chairman of the ECB or Richard Fisher, head of the Federal Reserve Bank of Dallas.

Rational expectations equilibrium (REE) models would lend themselves naturally to studying such questions. However, virtually all such models assume (for tractability) that the rate of interest is exogenous, thus ruling out learning from interest rates. Accordingly, we develop a novel REE model in which the interest rate is endogenous and utilized by investors to update their beliefs. We then study how informational efficiency correlates with the interest rate. Finally, we vary bond-market characteristics to study the implications of fiscal and monetary policies for informational and real (allocative) efficiency, as well as, for asset prices.

Specifically, ours is a standard REE model, in the spirit of Grossman and Stiglitz (1980), Hellwig (1980), and Verrecchia (1982), with a single risky stock and a (real) risk-free bond. However, there exists one key difference: the rate of interest is determined endogenously by supply and demand; in other words, we relax the common assumption that the bond is in perfectly elastic supply. As a consequence, the equilibrium interest rate now plays a dual role: it is used to discount future cashflows but also reveals information to investors. Noise (liquidity) traders, represented by a noisy supply, operate in *both* markets, thus preventing the combination of the two asset prices from being perfectly revealing. Intuitively, shocks to the bond's supply represent "discount rate news" (since they affect expected returns but not cashflows), whereas shocks to the stock's payout can be interpreted as "cashflow news." Finally, to allow for consumption goods rather than the bond to serve as numéraire (so that the bond price is not simply a normalization), we assume that investors derive utility not only from terminal but also from initial consumption.[3,4]

We demonstrate that, while the bond market does not provide information about the stock's payoff, it does reveal valuable information about the stock's supply, which, in turn, allows investors to extract more information about the stock's payoff from its price. Put differently, the bond market conveys information about discount rates which makes the stock

[3] In traditional REE model, the (exogenous) bond serves as numéraire, that is, the stock price is expressed in units of the bond or, put differently, the bond price is normalized to one.

[4] In the presence of initial consumption, equilibrium prices are a nonlinear functions of the state variables. Hence, we identify the equilibrium numerically. To illustrate the key economic mechanism, we start by briefly studying a version of our model without initial consumption that yields closed-form expressions for investors' posterior beliefs. Notably, in this setup, we are able to characterize the equilibrium in closed-form even though prices are non-linear functions of the state variables.

price more informative about cashflows. To understand the mechanism at work, observe that investors' aggregate demand for bonds depends on their aggregate income, in particular income from the stock, which is itself a function of the stock's supply. In equilibrium, the interest rate equates that demand with the supply of bonds, and thereby links together the supplies of the stock and bond. In that way, the rate of interest serves as a signal about the stock supply, with the bond supply acting as a source of noise. Importantly, the link between the supplies is denominated in value, i.e., in units of the good, so a higher interest rate (or, equivalently, a lower bond price) implies a less noisy value of the bond's supply, and a higher signal-to-noise ratio. With dampened bond noise, the interest rate is a more accurate signal of the stock's supply. In the limiting cases of an infinite interest rate or a known bond supply, the bond noise vanishes entirely and so the interest rate reveals the stock supply perfectly (absent other sources of noise).

Through this mechanism, investors use the interest rate to update their beliefs about the stock supply (discount rate), which in turn, allows them to extract more cashflow-relevant information from the stock's price. Strikingly, this mechanism implies that, even under a totally uninformative prior about the stock supply (i.e., with infinite variance), the stock price provides information about the payoff (because its variance conditional on the bond signal is finite).

We then study how characteristics of the bond market, namely the mean and precision of the bond supply, affect equilibrium asset prices and their informativeness. Intuitively, the interest rate is increasing in the mean bond supply as a higher supply requires a lower bond price for the market to clear. It follows that price informativeness is also increasing in the mean bond supply—an increase that can be entirely attributed to learning from interest rates. These changes in the equilibrium interest rate and price informativeness, naturally, have an impact on stock-return moments. A higher price informativeness (caused by a higher mean supply) leads to less risk and therefore to a lower expected excess return, a lower return volatility, and a lower price of risk for the stock. It also implies a reduction in the correlation between stocks' excess returns. To the extent that interest rates are cyclical, these results imply that the level and price of risk as well as the volatility and comovement of stock returns are all countercyclical, consistent with the data.

We also illustrate the *real* effects of learning from interest rates. For that purpose, we embed our REE framework into a production economy, allowing for endogenous investment and output. We document that, in environments with high interest rates, firms make more *efficient* investment decisions. That is, thanks to higher price informativeness, firms are better able to differentiate high-productivity from low-productivity states which unambiguously increases real (allocative) efficiency in the economy.

In the last step of our theoretical analysis, we incorporate a government, specifically, government spending and taxation, as well as money, into the economy. This allows us to speak to the influence of fiscal and monetary policies on informational (and allocative) efficiency and offers the additional benefit of "closing" the model (i.e., it ensures that any changes in the bond supply are matched with offsetting changes in either government spending, seignorage, or tax proceeds). We capture the usefulness of money as a medium of exchange by introducing real-money balances in investors' utility function. As in the stock and bond markets, we assume that the supply of money is noisy which injects additional noise into the bond signal. Offsetting the increased noisiness of the bond signal, investors now observe another signal, namely, the inflation rate which also contains information about the stock supply.[5] Hence, both the rates of interest and inflation allow investors to form more precise posterior beliefs about the discount rate (the stock's supply) which, in turn, allows them to extract more cashflow information from the stock's price. An additional outcome of the model is that more transparent policies (modelled as a more precise supply of bonds or money) allow the government to enhance price informativeness without having to increase the mean bond or money supply; put differently, transparency makes policy implementation more efficient.

Overall, our theoretical analyses generate a rich set of novel predictions that are consistent with broad features of the data. For instance, informational and allocative efficiency increase in the real interest rate (and in the bond and money supplies)—in line with the

[5] In the presence of money, money, rather than the good, serves as a numéraire.

empirical evidence presented in Section 1. Moreover, consistent with well-known stylized asset-pricing facts, our model predicts—holding fixed fundamentals—an increase in the market price of risk, as well as, in the mean and variance of excess returns, during economic downturns (represented by periods of low interest rates). In addition, stocks (endogenously) comove more during downturns.

Our paper spans several strands of the literature. First and foremost, it builds on the extensive noisy REE literature initiated by Grossman and Stiglitz (1980) and Hellwig (1980). Our main contribution to this literature is to endogenize the rate of interest. We show that the interest rate contains valuable information about the stock's noisy supply, and work out how investors use this information to update their beliefs about its payoff. We are not aware of any other work in which the stock price and the interest rate *both* reveal information. A consequence is that price informativeness and investors' posterior precision are increasing functions of the interest rate. This property, in turn, further distinguishes ours from most noisy REE models. In particular, the informativeness of stock prices varies along the business cycle. This finding links our work to that of Kacperczyk, van Nieuwerburgh, and Veldkamp (2016) who analyse how investors' knowledge depends on the state of the economy. But the mechanisms are markedly different in that this dependence stems from (exogenous) variations in risk and in its price (Kacperczyk, van Nieuwerburgh, and Veldkamp 2016) versus from (endogenous) variations in interest rates (our model). As a result, investors' posterior precision is also stochastic and, hence, *ex-ante* unknown (in contrast to traditional models with Gaussian shocks).

Our paper relates further to three sub-streams of the noisy REE literature. The first studies economies with multiple assets such as Admati (1985), Brennan and Cao (1997), Kodres and Pritsker (2002), van Nieuwerburgh and Veldkamp (2009, 2010), Biais, Bossaerts, and Spatt (2010), and Kacperczyk, van Nieuwerburgh, and Veldkamp (2016). Though our model features two assets with informative prices, it differs distinctly from these models in that our other asset is *riskfree*. In particular, we show that the riskfree asset reveals information about the stock despite its payoff and supply being *uncorrelated* with those of the stock. This is in sharp contrast to Admati (1985) and the work that followed, in which, absent cross-asset correlations, nothing is to be learned from one asset about another. Note also that these model lead to a deterministic price informativeness, whereas it is stochastic in our framework. Second, through its emphasis on information about the stock's *supply*, our work is also related to papers such as Watanabe (2008), Ganguli and Yang (2009), Manzano and Vives (2011), Farboodi and Veldkamp (2019), and Yang and Zhu (2019). In these papers, investors receive a private and exogeneous signal (which they either purchase or are endowed with) about the stock supply. In contrast, the supply signal—also referred to as (order-)flow or discount rate information in this literature—is public and endogenous in our setup. Finally, our paper is part of the sub-stream of the literature that seeks to generalize noisy REE models and explore their robustness to assumptions (see, e.g., Barlevy and Veronesi 2000, 2003, Peress 2004, Breon-Drish 2015, Banerjee and Green 2015 and Albagli, Hellwig, and Tsyvinski 2015). Our contribution is to endogenize the interest rate in an otherwise standard noisy REE model and identify what features survive or differ.

The second stream of research to which our paper belongs studies the importance of an *endogenous* rate of interest in asset-pricing models under *symmetric* information. Lowenstein and Willard (2006) highlight that, under the assumption of a storage technology (i.e., riskless asset) in perfectly elastic supply, aggregate-consumption risk differs from exogenous fundamental risk and that this can yield misleading conclusions (e.g., with respect to the impact of noise traders or violations of the Law of One Price). Our work is distinctly different from their paper due to the presence of private information and our focus on price informativeness. Moreover, we find that the main conclusions of the traditional noisy REE literature are robust to endogenizing the interest rate. Instead, we illustrate that new (unexplored) mechanisms arise when the bond market clears under a fixed bond supply.

Finally, our work relates to the literature studying the impact of fiscal and monetary policy on stock prices.[6] While this literature typically assumes symmetric information, we allow for private (asymmetric) information. In so doing, we can analyse the impact of these

[6] Most of the fiscal-policy literature has examined its impact on the business cycle (see, among others, Dotsey 1990, Baxter and King 1993, and Ludvigson 1996). The implications of fiscal policies for stock prices are studied by Croce, Nguyen, and Schmid (2012), Croce, Kung, Nguyen, and Schmid (2012), Pástor and Veronesi (2012), and Gomes, Michaelides, and Polkovnichenko (2013). In addition, Lucas (1982), LeRoy (1984a,b), Svensson (1985), Danthine and Donaldson (1986), and Marshall (1992) study how changes in monetary policy affect real and nominal asset prices. Sellin (2001) provides a survey on the topic.

policies on the informational and allocative efficiency of the stock market. Moreover, a large literature in macroeconomics studies the impact of financial frictions, in particular, credit constraints, on capital misallocation and real efficiency.[7] Empirically, Gopinath, Kalemli-Özcan, Karabarbounis, and Villegas-Sanchez (2017) document a simultaneous decline in the real interest rate and capital-allocation efficiency in Southern European countries. In contrast, the frictions we consider operate in the stock market (asymmetric information).

The remainder of the paper is organized as follows. Section 1 discusses novel empirical findings motivating our theoretical analysis. Section 2 introduces our main economic framework. Section 3 discusses, in a tractable version of the model, the economic mechanism through which investors learn from the interest rate. In Section 4, we then study the full model and relate the characteristics of the bond market to equilibrium outcomes. Sections 3 and 6 explore, respectively, the real effects of learning from the interest rate and the impact of government policies. Finally, Section 7 concludes. Proofs and a description of the numerical solution approach are delegated to the Appendix.

1 Empirical Patterns in Price Informativeness

In this section, we offer novel empirical evidence on the relation between the informativeness of stock prices and characteristics of the bond market. In particular, we document patterns in price informativeness linked to the supply of and demand for Treasury bonds—patterns which guide the theory presented in the next sections.

1.1 Data and Estimation Procedures

Our analysis focuses on the U.S. market over the period from 1962 to 2017. Table A1 in Appendix B reports summary statistics for variables of interest.

Price Informativeness: We measure the informativeness of stock prices using the proxy developed by Bai, Philippon, and Savov (2016) which captures the extent to which firms'

[7] See, e.g., Bernanke and Gertler (1989) and Kiyotaki and Moore (1997). On the impact of frictions on asset prices, see among others, Brunnermeier and Pedersen (2008), Rampini and Viswanathan (2010), He and Krishnamurthy (2013), Biais, Hombert, and Weill (2014), and Brunnermeier and Sannikov (2014).

current stock prices reflect their future cash flows and, hence, directly relates to capital-allocation efficiency and aggregate welfare. Specifically, in each year, we run the following cross-sectional regression of year-$t+h$ earnings on year-t stock prices:

$$\frac{E_{j,t+h}}{A_{j,t}} = a_{t,h} + b_{t,h} \log\left(\frac{M_{j,t}}{A_{j,t}}\right) + c_{t,h}\, X_{j,t} + \epsilon_{j,t,h}, \tag{1}$$

where h denotes the forecasting horizon; $E_{j,t+h}/A_{j,t}$ denotes firm j's earnings before interest and taxes (EBIT) in year $t+h$ scaled by year-t total assets; $M_{j,t}/A_{j,t}$ denotes firm j's market capitalization (i.e., stock price times number of shares outstanding) in year t scaled by year-t total assets; and $X_{j,t}$ denotes a set of firm-level controls, namely current earnings, $E_{j,t}/A_{j,t}$, and industry fixed effects (one-digit SIC codes).[8] Intuitively, the coefficient $b_{t,h}$ reflects how closely current stock prices track future earnings and, hence, how much fundamental information is capitalized in stock prices.

Price informativeness at horizon h, $PI_{t,h}$, is measured as the coefficient estimate $b_{t,h}$ multiplied by the year-t cross-sectional standard deviation of (scaled) stock prices:

$$PI_{t,h} = b_{t,h}\, \sigma_t \left(\log\left(\frac{M_{j,t}}{A_{j,t}}\right)\right). \tag{2}$$

As shown in Bai, Philippon, and Savov (2016), $PI_{t,h}$ captures the (square root of the) variance of the predictable component of firms' payoffs Π_j given prices: $\mathbb{V}\mathrm{ar}(\mathbb{E}[\Pi_j|P_j])$. Hence, it serves as a natural proxy for forecasting price efficiency.

We obtain stock-price data from the Center for Research in Security Prices (CRSP) and accounting data from Compustat. As Bai, Philippon, and Savov (2016), we focus on S&P500 non-financial firms whose characteristics have remained remarkably stable over time[9] and on forecasting horizons (h) of 3 and 5 years—horizons that, from a capital-

[8] To align price informativeness with bond-market characteristics, stock prices are sampled at the end of the U.S. government's fiscal year (either June or September). For each firm, accounting variables are measured at the end of the previous fiscal year—typically December—to ensure that the information is readily available to market participants. We adjust earnings using the GDP deflator from the Bureau of Economic Analysis (BEA).

[9] In contrast, as shown in Bai, Philippon, and Savov (2016), the characteristics of non-S&P500 firms have changed dramatically over time, rendering any time-series analysis potentially misleading. Moreover, S&P500 firms represent the bulk of the market capitalization of the U.S. corporate sector.

allocation perspective, are most important (cf. the time-to-build literature, e.g., Koeva 2000) and for which prices are particularly useful in predicting earnings (as reported in Bai, Philippon, and Savov 2016).

Bond-market Characteristics: Our measures of bond-market characteristics closely follow Krishnamurthy and Vissing-Jorgensen (2012). U.S. real interest rates are obtained by deducting expected inflation from long-term nominal rates. The nominal rate on long-maturity Treasury bonds is measured as the average yield on government bonds with a maturity of 10 years and longer (up to 1999) and the 20-year Treasury constant-maturity rate (from 2000 on), both obtained from the Federal Reserve's FRED database. Expected inflation is estimated using a simple random-walk model (applied to the Consumer Price Index of the BEA).[10]

To measure the supply of U.S. Treasuries, we use the U.S. government debt-to-GDP ratio, specifically, the ratio of the market value of publicly-held government debt to GDP. For that purpose, we adjust the book (par) value of U.S. government debt (obtained from the Treasury Bulletin) using the Treasury-debt market-price index provided by the Dallas Fed. Government debt and, accordingly GDP, are measured at the end of the government's fiscal year (i.e., the end of June up to 1976 and the end of September from 1977 on).[11] To account for the strong demand for U.S. Treasury bonds in recent years—in particular, following the 2007-09 financial crisis—we complement the measure of Treasury supply with two instruments for Treasury demand: (1) the holdings of Mortgage-backed securities (MBS) by the Federal Reserve banks and (2) the holdings of Treasury securities by the Federal Reserve banks. Both are scaled by U.S. GDP and based on data from the Federal Reserve System. Finally, we measure U.S. money supply as the M2 Money Stock, retrieved from the Federal Reserve's FRED database.

[10]The random-walk model delivers the best out-of-sample performance for predicting inflation over our sample period. Our findings are robust to the use of alternative models for expected inflation, namely AR(1) and ARMA(1,1) models.

[11]Our results remain unchanged when using the debt-to-GDP series prepared by Krishnamurthy and Vissing-Jorgensen (2012). In fact, the correlation between the two data series is 0.9966. We are grateful to the authors for sharing their data with us.

Control Variables: We estimate stock-market and cashflow (fundamental) volatility as, respectively, the annualized standard deviation of daily S&P500 returns over the past 12 months, and the cross-sectional standard deviation of firms' (scaled) earnings ($E_{j,t}/A_{j,t}$).

1.2 Price Informativeness and Bond-Market Characteristics

In a first step, we analyse the relation between the informativeness of stock prices and the real interest rate. Panel A of Figure 1, which plots five-year price informativeness, PI_5, against the real interest rate, strongly suggests a positive correlation between the two series.[12] A corresponding regression of price informativeness on the real interest rate confirms that this positive relation is statistically significant, with a slope coefficient of 0.179 (t-statistic of 2.67). In terms of economic magnitude, a one standard-deviation (SD) increase in real interest rate leads to a 0.42 SD increase in price informativeness.

A limitation of this test is that the rate of interest is endogenous—determined in equilibrium jointly with other quantities, including price informativeness. Hence, our main analysis focuses instead on the relation between price informativeness and proxies for Treasury supply and demand. Indeed, it seems implausible that the government chooses its debt level, or that the Federal Reserve Banks choose their MBS or Treasury holdings according to the informativeness of stock prices. Table 1 reports the results of our regression analyses. The dependent variable in each regression is price informativeness (typically PI_5) and the primary explanatory variable is the Treasury-bond supply. In general, we include a proxy for bond demand which has picked up substantially following the recent financial crisis (see, e.g., Andolfatto and Spewak 2018). The regressions in Table 1 are estimated using ordinary least squares (OLS), with standard errors adjusted for serial correlation using the Newey-West procedure with five lags.[13]

The baseline regression in Column 1 shows that there exists a significant positive relation between price informativeness and bond supply (t-statistic of 3.18). Changes in bond supply

[12] Our time-series of price informativeness ends in 2012 because we need to forecast 5-year-ahead earnings which go until 2017.

[13] Our choice of lags is based on two considerations. First, price informativeness is measured from overlapping regressions, with a maximum overlap of five years for earnings in the case of PI_5. Second, the optimal lag-selection procedure of Newey and West (1994) recommends lags between 3 and 5 years. Our results are robust to alternative specifications.

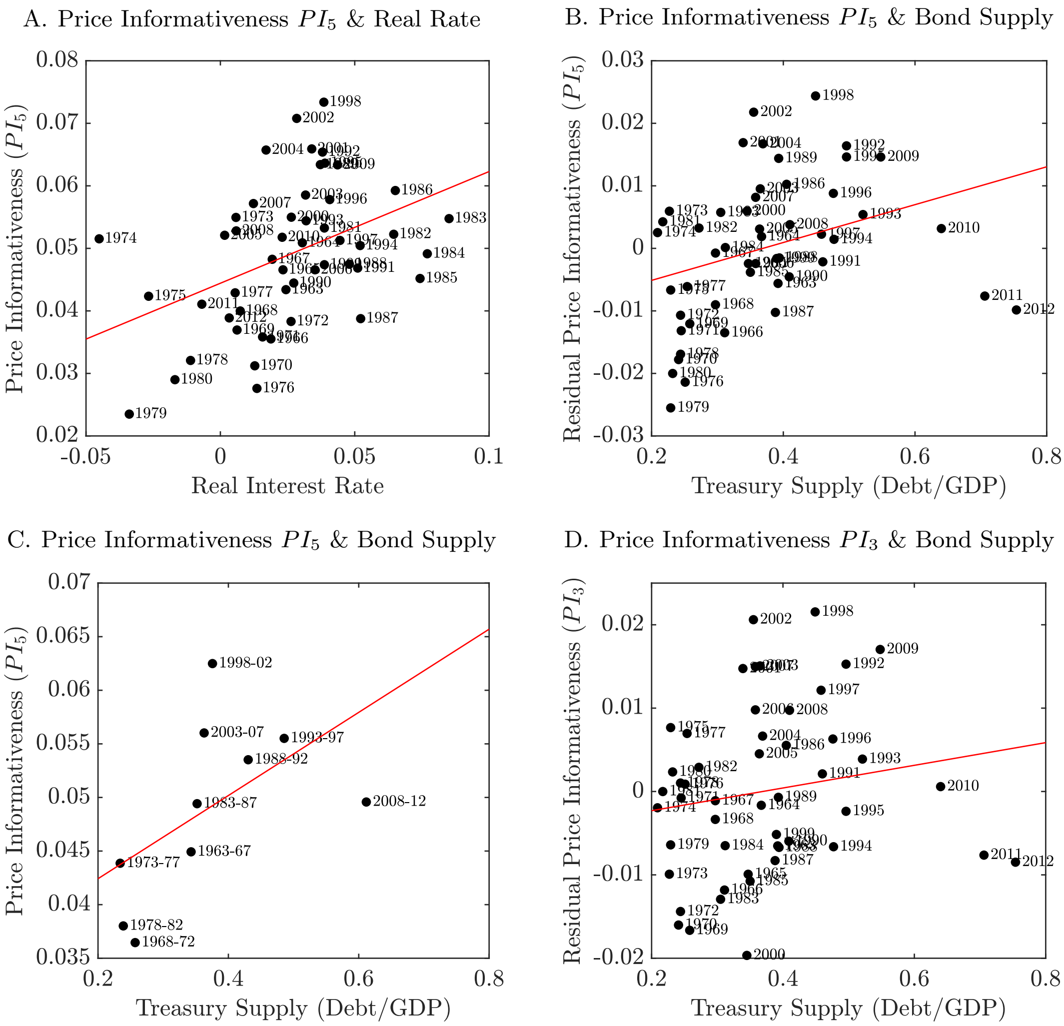

Figure 1: Empirical Patterns in Stock-Price Informativeness. The figures plot price informativeness against the real interest rate (Panel A) and the debt-to-GDP ratio (Panels B to D). The sample consists of annual observations from 1963 to 2012. Panel A plots price informativeness against the real interest rate. Panels B and D plot the residuals of a univariate regression of price informativeness (PI_5 and PI_3, respectively) on the Federal Reserve Banks' MBS holdings, against the debt-to-GDP ratio. Panel C plots the 5-year average of price informativeness, $\bar{P}I_5$, against the corresponding 5-year average of the debt-to-GDP ratio. All graphs also display a solid line representing the fitted values of a univariate regression of the y-axis variables on the x-axis variables.

have an economically sizeable effect on price informativeness; for example, all else equal, an one-SD increase in the debt-to-GDP ratio (from its mean value of 0.3830 to 0.4940) increases price informativeness by 15 percent (0.64 SD)—suggesting a strong improvement in capital-allocation efficiency and, hence, welfare. This positive relation is illustrated in Panel B of Figure 1 which plots residual price informativeness (i.e., the residuals of a univariate regression of price informativeness on Treasury demand) against Treasury supply.

Consistent with a positive correlation between price informativeness and Treasury *supply*, Column 1 also documents a strong negative correlation between price informativeness and bond *demand*, measured by the FEDs' MBS holdings (t-statistic of -2.29). Specifically, all else equal, an increase in the FEDs' MBS holdings from its mean of 0.005 to 0.06 (mean following QE) lowers price informativeness by more than 35 percent or 1.61 SD.

The remainder of Table 1 confirms that our findings hold up to a series of robustness checks. Column 2 focuses on a period, 1962-2009, over which Treasury demand was constant and so does not need to be controlled for.[14] Column 3 (also illustrated in Panel C) exploits only low-frequency variations in the series; that is, reports results of a regression of (non-overlapping) five-year averages of the variables (i.e., a total of 10 data points). Column 4 uses the FEDs' Treasury holdings (instead of their MBS holdings) to control for Treasury demand. Column 5 lags bond supply and demand. Columns 6 and 7 control for stock-market and cashflow volatility, respectively. In Column 8, we include money supply as an additional explanatory variable. While both bond supply and demand remain statistically significant, some of the positive impact of bond supply on price informativeness shifts to money supply. Finally, Column 9 (also illustrated in Panel D) uses, PI_3, the price-informativeness measure based on a 3-year forecasting horizon.

Taken together, the regressions in Table 1 provide robust empirical evidence that price informativeness correlates positively with Treasury supply (and money supply) and negatively correlated with bond demand. These results pose a substantial challenge to traditional information-choice models and motivate our subsequent theoretical analysis.

2 A REE-Model with Bond-Market Clearing

In this section, we introduce our main economic framework. The framework differs from traditional competitive rational expectation equilibrium (REE) models, such as Grossman and Stiglitz (1980), Hellwig (1980), and Verrecchia (1982), along three key (related) dimensions. First, the rate of interest is determined endogenously. Second, investors learn not

[14]For example, Gorton, Lewellen, and Metrick (2012) document that the demand for "safe" (information-insensitive) debt has been constant during this period.

	Base	1963-2009	5-year periods	FED: Treasury	Lagged variables	Volatility Controls		PI_3
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Debt/GDP	0.060***	0.074***	0.079***	0.048***	0.066***	0.063***	0.061***	0.033**
	[3.13]	[4.97]	[3.24]	[3.40]	[4.09]	[3.21]	[3.34]	[1.98]
FED Hold./GDP	-0.331***		-0.452**	-0.364***	-0.421***	-0.369***	-0.359***	-0.248**
	[-2.52]		[-2.27]	[-3.38]	[-5.45]	[-2.55]	[-3.21]	[-2.36]
S&P500 Vola.						0.028		0.037
						[0.81]		[1.03]
Cashflow Vola.							0.664***	0.506***
							[3.12]	[2.45]
R^2	0.211	0.336	0.600	0.228	0.260	0.226	0.350	0.235
Observations	50	46	10	50	50	50	50	50

Table 1: Impact of Bond Supply and Demand on Stock-Price Informativeness. The table reports results of regressions relating price informativeness to Treasury-bond supply and demand. The dependent variable is 5-year price informativeness, PI_5, (except in Column 10 which is based on 3-year price informativeness, PI_3). *Debt/GDP* is the ratio of the market value of Treasury debt held by the public to U.S. GDP. *FED Hold./GDP* is the ratio of the Federal Reserve banks' holdings of MBS (or Treasury in Column 4) divided by U.S. GDP. *S&P500 Vola.* and *Cashflow Vola.* are measures of volatility of, respectively, the S&P500 returns and firms' earnings. Regressions are estimated using OLS and standard errors are adjusted for serial correlation using the Newey-West procedure with five lags. We report t-statistics in brackets. *, **, and *** indicate significance at the 10%, 5%, and 1% level.

only from their private signals and the stock price but also from the interest rate. Third, agents consume not only in the final period, but also in the trading period. In the following, we discuss the details of the model.

Information Structure and Timing

We consider a two-period model. Figure 1 illustrates the sequence of the events. In period 1, investors observe their private signals and equilibrium asset prices. Based on this information, they choose their portfolio holdings and (period-1) consumption (which we dub initial consumption). Both asset prices are set such that financial markets clear. In period 2, investors simply consume the proceeds from their investments (terminal consumption). We denote rational investors' expectation and variance conditional on their time-1 information set $\mathcal{F}_i$ as $\mathbb{E}[\,\cdot\,|\,\mathcal{F}_i]$ and $\mathbb{V}\mathrm{ar}(\,\cdot\,|\,\mathcal{F}_i)$.

Investment Opportunities

Two financial securities are traded in competitive markets: a (real) riskless asset (the "bond") and a risky asset (the "stock"). The consumption good serves as numéraire, hence

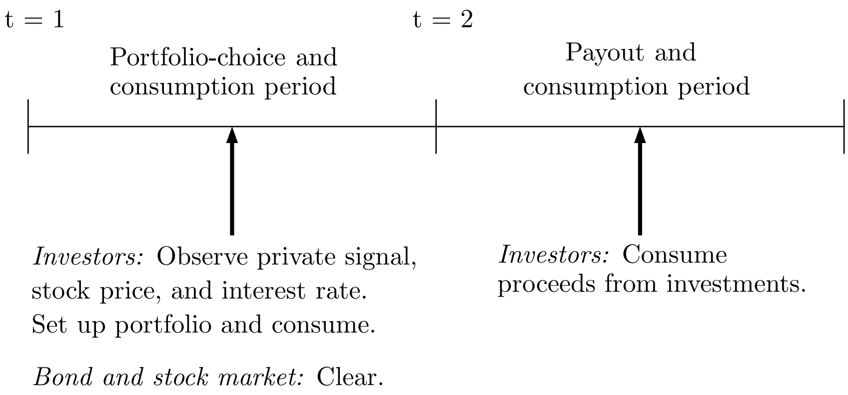

Figure 2: Timing. The figure illustrates the sequence of the events.

all prices and payoffs are denominated in units of the good. The bond has a payoff of one in period 2, with a (gross) rate of interest R_f or, equivalently, a price $1/R_f$.[15] The stock is a claim to a random payoff $\Pi \sim \mathcal{N}(\mu_\Pi, 1/\tau_\Pi)$, which is only observable in period 2, and its price is denoted by P.[16] The stock also makes a deterministic payout of Π_1 in period 1 (initial dividend). Both assets are in inelastic (finite) supply.

Investors

There exists a continuum of atomless investors with unit mass. At the beginning of period 1, each investor i receives a private signal $S_i = \Pi + \varepsilon_i$, $\varepsilon_i \sim \mathcal{N}(0, 1/\tau_\varepsilon)$ with precision τ_ε. Investors have CARA-preferences over initial and terminal consumption, $C_{i,1}$ and $C_{i,2}$

$$U_i(C_{i,1}, C_{i,2}) = -\frac{1}{\gamma} \exp\big(-\gamma\, C_{i,1}\big) + \beta\, \mathbb{E}\left[-\frac{1}{\gamma} \exp\big(-\gamma\, C_{i,2}\big) \,\big|\, \mathcal{F}_i\right], \tag{3}$$

where γ denotes absolute risk-aversion, $\beta \in (0,1]$ denotes the rate of time preference and $\mathcal{F}_i = \{S_i, P, R_f\}$ describes investor i's time-1 information set. Each investor is endowed with a random number shares of the stock, $X_{i,0}$ and no shares of the bond. Thus, initial wealth is given by $W_{i,1} = X_{i,0}\,(P + \Pi_1)$.

[15]This contrasts with traditional REE models, such as Grossman and Stiglitz (1980), Hellwig (1980), and Verrecchia (1982), in which the (exogenous) riskless bond serves as numéraire.

[16]Throughout the paper, we use the letter τ to denote precisions (inverse of variances).

In addition, noise (liquidity) traders operate in *both* the bond and stock market. Their behaviour is not explicitly modelled and characterized instead by the (random and unobservable) residual supplies of the two assets. These residual supplies should be understood as the supply of an asset minus the noise traders' demand. Formally, the residual supply of the stock and bond are represented by exogenous random variables $\theta_X \sim \mathcal{N}(\mu_{\theta_X}, 1/\tau_{\theta_X})$, and $\theta_Y \sim \mathcal{N}(\mu_{\theta_Y}, 1/\tau_{\theta_Y})$. μ_{θ_X} (resp. μ_{θ_Y}) and τ_{θ_X} (resp. τ_{θ_Y}) denote the mean and prior precision of the stock's (resp., bond's) supply. While the aggregate number of endowed shares, $\int X_{i,0}\, di$, equals the residual supply of the stock, we assume that each investor's endowment is uninformative.[17] The random variables Π, θ_X, and θ_Y are assumed to be uncorrelated. Note that, in addition to the usual stock-market noise, we assume that the supply of the bond is noisy. This prevents the bond and stock prices from being jointly perfectly revealing.

Equilibrium Definition

The objective of investor i is to maximize expected utility (3) subject to the following budget equations:

$$C_{i,1} + X_i\, P + Y_i\, R_f^{-1} = W_{i,1}, \qquad \text{and} \qquad C_{i,2} = X_i\, \Pi + Y_i, \tag{4}$$

where X_i and Y_i denote the investor's holdings (number of shares) of the stock and the bond, respectively.

Accordingly, a rational expectations equilibrium is defined by consumption choices $\{C_{i,1}, C_{i,2}\}$, portfolio choices $\{X_i, Y_i\}$, and asset prices $\{P, R_f\}$ such that:

1. $\{C_{i,1}, C_{i,2}\}$ and $\{X_i, Y_i\}$ maximize investor i's expected utility (3) subject to the budget constraints (4), taking prices P and R_f as given.
2. Investors' expectations are rational.

[17] This rules out learning from the initial stock endowment which, otherwise, would also serve as an additional signal. This assumption can be rationalized by assuming that the variance of endowment shocks across investors is infinite.

3. Aggregate demand equals aggregate supply—in the bond and the stock market:

$$\int X_i \, di = \theta_X, \text{ and } \int Y_i \, di = \theta_Y. \tag{5}$$

It is important to highlight that, in equilibrium, *both* asset prices play a dual role: each price clears its respective market but also aggregates and transmits investors' private information.

3 Learning from the Interest Rate: Economic Mechanism

In this section, we illustrate *how* investors learn from the rate of interest. For that purpose, we rely on a version of our model that provides the key economic intuition and allows for closed-form solutions. It differs from the framework described in the preceding section along a single dimension: Investors consume exclusively at the terminal date.

3.1 Equilibrium

In the absence of initial consumption, the objective of each investor i is to choose her portfolio holdings in the stock, X_i, and in the bond, Y_i, in order to maximize expected utility over terminal consumption:

$$U_i(C_{i,2}) = -\frac{1}{\gamma} \mathbb{E}\left[\exp\big(-\gamma \, C_{i,2}\big) \,\big|\, \mathcal{F}_i\right], \tag{6}$$

subject to the budget equations

$$X_i \, P + Y_i \, R_f^{-1} = W_{i,1} \quad \text{and} \quad C_{i,2} = X_i \, \Pi + Y_i. \tag{7}$$

Solving for investors' optimal asset demand, aggregating their demand, and imposing market-clearing in both markets (5), yields the following characterization of the equilibrium:

Theorem 1. *There exists a unique (conditionally linear) rational expectations equilibrium. The equilibrium asset prices are given by:*

$$R_f = \frac{\theta_Y}{\Pi_1\,\theta_X}; \qquad \textit{and} \tag{8}$$

$$R_f\,P = \left(\frac{\tau_\Pi}{\tau}\,\mu_\Pi + \frac{\tau_\epsilon\,\tau_{\theta_X|R_f}}{\gamma\,\tau}\,\mu_{\theta_X|R_f}\right) + \frac{\tau_\epsilon\left(\gamma^2 + \tau_\epsilon\,\tau_{\theta_X|R_f}\right)}{\tau\,\gamma^2}\left(\Pi - \frac{\gamma}{\tau_\epsilon}\,\theta_X\right), \tag{9}$$

$$\textit{with} \quad \tau \equiv \tau_\Pi + \tau_\varepsilon + (\tau_\varepsilon/\gamma)^2\,\tau_{\theta_X|R_f}, \quad \tau_{\theta_X|R_f} \equiv \tau_{\theta_X} + R_f^2\,\Pi_1^2\,\tau_{\theta_Y},$$

$$\textit{and} \quad \mu_{\theta_X|R_f} \equiv \frac{\tau_{\theta_X}}{\tau_{\theta_X|R_f}}\,\mu_{\theta_X} + \frac{R_f^2\,\Pi_1^2\,\tau_{\theta_Y}}{\tau_{\theta_X|R_f}}\,\frac{\mu_{\theta_Y}}{R_f\,\Pi_1}.$$

Investor i's optimal stock and bond holdings equal:

$$X_i = \frac{\mathbb{E}[\Pi\,|\,\mathcal{F}_i] - P\,R_f}{\gamma\,\mathbb{V}ar(\Pi\,|\,\mathcal{F}_i)} \qquad \textit{and} \qquad Y_i = R_f\,\big(W_{i,1} - X_i\,P\big). \tag{10}$$

The optimal demand for the stock, X_i, in (10) follows the standard mean-variance portfolio rule. It is independent of the investor's initial wealth, $W_{1,i}$, and positively related to her posterior mean and precision. In contrast, the optimal demand for the bond, Y_i, in (10) is a function of the investor's initial wealth, $W_{1,i}$, and, through her stock demand, X_i, inversely related to her posterior mean and precision. For instance, all else equal, the demand for the bond is low (even negative if the investor borrows to finance stock purchases) for an investor who is optimistic regarding the stock's future payoff, Π.

The interest rate, R_f, in (8) is a function of the realized stock and bond supplies and, thus, stochastic.[18] As expected, it is increasing in the bond supply, θ_Y; specifically, a larger supply requires a lower bond price for the market to clear and, hence, a higher interest rate. Conversely, the interest rate is declining in the stock supply, θ_X, and the initial payout of the stock, Π_1. Intuitively, a larger stock supply or a higher initial stock payout leads

[18]The gross interest rate R_f can be negative in this framework. It does not, however, lead to arbitrage opportunities. Indeed, negative rates are caused by the fact that investors have a preference over terminal consumption only and, consequently, the interest rate is not determined by marginal utilities. In Section 4, we demonstrate that allowing for initial consumption (in which case the gross interest rate is always positive) does not affect any of our results.

to a higher aggregate initial endowment, that is, to a larger supply of consumption goods. Because these serve as numéraire, the bond price increases and the interest rate drops. Put differently, a higher aggregate endowment increases the demand for bonds since this endowment must be saved (recall, here, investors only consume in the second period).

The equilibrium price ratio, $R_f\, P$, in (9) has the familiar structure of, for example, Hellwig (1980) and Verrecchia (1982). There is only one important difference: it features the *posterior* mean and precision of the *stock supply*, $\mu_{\theta_X|R_f}$ and $\tau_{\theta_X|R_f}$, instead of (traditionally) its prior mean and precision (μ_{θ_X} and τ_{θ_X}). This difference arises because investors can use information revealed by the interest rate to update their beliefs about the stock's supply (i.e., have access to discount-rate news). In particular, since there is no consumption in period-1, in equilibrium, aggregate income from the stock ($\Pi_1 \theta_X$) must equal aggregate demand for the bond (θ_Y / R_f) or, formally:

$$0 = \theta_X - \frac{\theta_Y}{R_f\, \Pi_1}. \tag{11}$$

This equation links together the supplies of the stock and bond. In that way, it serves as a signal about the stock supply, with the bond supply acting as a source of noise. Consequently, rational investors use the information revealed by the equilibrium interest rate, R_f, to update their prior beliefs regarding the stock supply, θ_X. This, in turn, helps them extract more information from the stock's price about the stock's payoff. The following Lemma describes the resulting distribution of the stock's supply conditional on observing the interest rate.

Lemma 1. *The distribution of the stock supply, θ_X, conditional on the equilibrium interest rate, R_f, is characterized by*

$$\mathbb{E}\left[\theta_X \mid R_f\right] = \mu_{\theta_X|R_f} = \frac{\tau_{\theta_X}}{\tau_{\theta_X|R_f}}\, \mu_{\theta_X} + \frac{R_f^2\, \Pi_1^2\, \tau_{\theta_Y}}{\tau_{\theta_X|R_f}}\, \frac{\mu_{\theta_Y}}{R_f\, \Pi_1}; \;\; \textit{and} \tag{12}$$

$$\mathbb{V}ar\left(\theta_X \mid R_f\right)^{-1} = \tau_{\theta_X|R_f} = \tau_{\theta_X} + R_f^2\, \Pi_1^2\, \tau_{\theta_Y}. \tag{13}$$

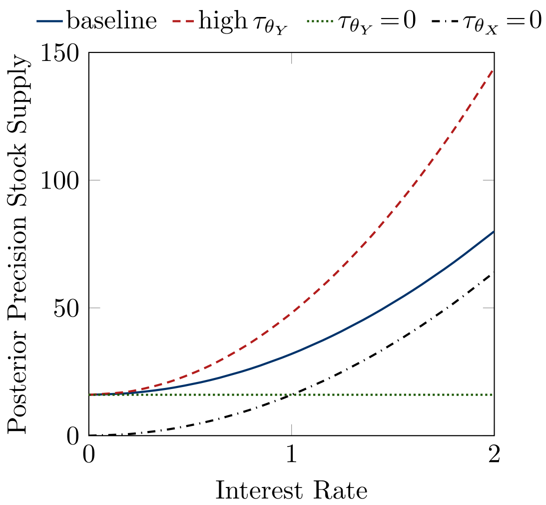

Figure 3: Posterior Precision of Stock Supply (*in the absence of initial consumption*). The figure plots the investors' posterior precision regarding the stock's supply, $\tau_{\theta_X|R_f}$, as a function of the interest rate R_f—for different levels of the prior precision of the bond supply, τ_{θ_Y}. The graphs are based on the following baseline parameter values: $\gamma = 1$, $\Pi_1 = 1$, $\mu_\Pi = 1$, $\tau_\Pi = 4^2$, $\tau_\epsilon = 0.5^2$, $\mu_{\theta_X} = 1$, $\tau_{\theta_X} = 8^2$, $\mu_{\theta_Y} = 0.5$, and $\tau_{\theta_Y} = 8^2$. High τ_{θ_Y} describes an economy with a higher precision of the bond supply; $\tau_{\theta_Y} = 0$ describes an economy in which investors do not learn from the rate of interest; and $\tau_{\theta_X} = 0$ describes an economy in which the (prior) stock supply is completely uninformative.

Intuitively, rational investors combine their prior beliefs with the signal provided by bond-market clearing to form "posterior" beliefs regarding the (unobservable) supply in the stock market. Using Bayesian updating, the posterior mean of the stock-market supply, $\mu_{\theta_X|R_f}$, in (12), is a precision-weighted average of the prior mean (μ_{θ_X}) and the mean conditional on the bond-market signal ($\mu_{\theta_Y}/(R_f\,\Pi_1)$). Similarly, the posterior precision, $\tau_{\theta_X|R_f}$, in (13), is the sum of the prior precision (τ_{θ_X}) and the precision of the bond-market signal ($R_f^2\,\Pi_1^2\,\tau_{\theta_Y}$).

An important property is that the posterior precision, $\tau_{\theta_X|R_f}$, is increasing in R_f (provided $\tau_{\theta_Y} > 0$), as Figure 3 illustrates. The reason is that Equation (11), which ties together the supplies of the stock and bond, is denominated in value, that is, in units of the good. Thus, a higher interest rate (or, equivalently, a lower bond price) implies a less noisy value of the bond's supply and, hence, a higher signal-to-noise ratio of the bond-market signal, $\Pi_1 R_f$.[19] In other words, with dampened bond noise, the interest rate is a more accurate signal of the stock's supply.

[19] Here and in the following, we define the signal-to-noise ratio as a signal's sensitivity to the quantity of interest ("fundamental") divided by its sensitivity to noise.

Intuitively, this learning effect is stronger, the higher the prior precision of the bond supply, τ_{θ_Y}. In fact, only if the bond supply is completely uninformative (i.e., $\tau_{\theta_Y} = 0$), is the interest rate completely uninformative. In that case, the conditional distribution of the stock supply collapses to its prior distribution.[20] Moreover, as illustrated in Figure 3, learning from the interest rate results in non-diffuse posterior beliefs regarding the stock's supply even if the prior stock supply is completely uninformative.

Also note that, because the interest rate R_f is stochastic, both the posterior mean (12) and posterior precision (13) are also stochastic and, hence, depend on the realization of the supplies in both markets (provided $\tau_{\theta_Y} > 0$). Hence, the coefficients of the price ratio (9) are also *stochastic*, that is, depend on the realization of the state. This is illustrated in Panels A and B of Figure 4 which plot the sensitivity of the price ratio to the stock's payoff and supply, respectively. Both sensitivities are increasing (in absolute value) with the interest rate R_f because this implies more precise beliefs about the stock supply. Moreover, the magnitude of the effect is increasing in the precision of the bond supply—with both sensitivities only being constant, as in Hellwig (1980), if the bond-market is completely uninformative ($\tau_{\theta_Y} = 0$).

Methodologically, we are able to characterize the equilibrium in closed-form—even though both the equilibrium interest rate and the equilibrium stock price are non-linear functions of the state variables (Π, θ_X and θ_Y)——in stark contrast to traditional frameworks in which the equilibrium stock price is a linear function of the state variables. As shown in Appendix C, the key idea is to stipulate ("conjecture") the functional form of the market-clearing conditions (which remain linear), instead of stipulating the functional form of the interest rate and the stock price (which are not linear). Intuitively, this means that investors extract information from the market-clearing conditions rather than from prices themselves. This makes it possible to solve the investors' inference problem in closed-form and, in turn, obtain closed-form expressions for all equilibrium quantities.

[20] As a result, the equilibrium price ratio, $R_f\, P$, coincides with that in Hellwig (1980). However, the interest rate remains stochastic, so that the equilibrium is not identical to Hellwig (1980)'s.

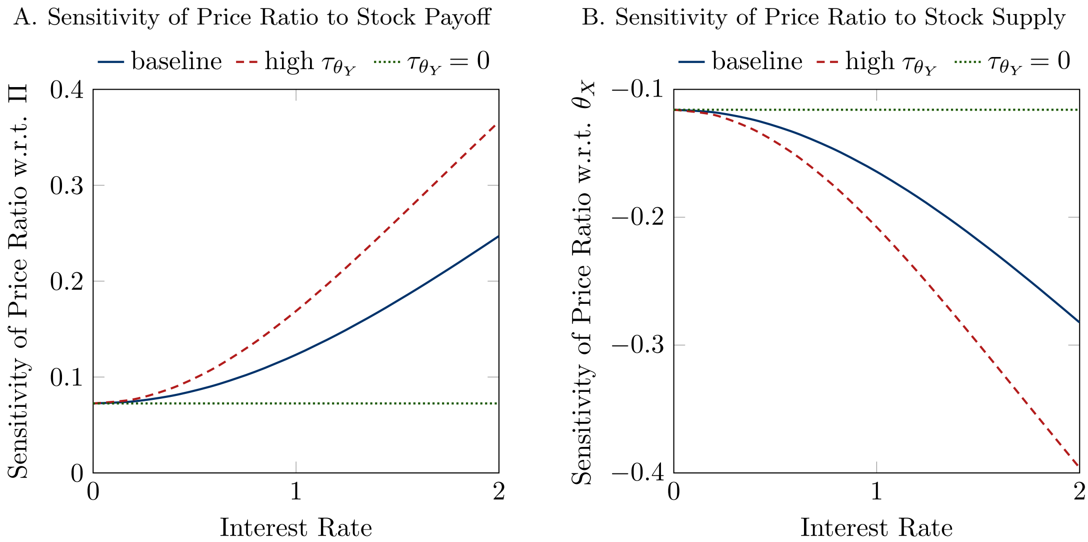

Figure 4: Price-Ratio Sensitivities (*in the absence of initial consumption*). The figure plots the sensitivity of the price ratio, $R_f\, P$, with respect to the stock payoff Π (Panel A) and the stock supply θ_X (Panel B), as functions of the interest rate R_f—for three different levels of the prior precision of the bond supply, τ_{θ_Y}. The graphs are based on the following baseline parameter values: $\gamma = 1$, $\Pi_1 = 1$, $\mu_\Pi = 1$, $\tau_\Pi = 4^2$, $\tau_\epsilon = 0.5^2$, $\mu_{\theta_X} = 1$, $\tau_{\theta_X} = 8^2$, $\mu_{\theta_Y} = 0.5$, and $\tau_{\theta_Y} = 8^2$. High τ_{θ_Y} describes an economy with a higher precision of the bond supply and $\tau_{\theta_Y} = 0$ describes an economy in which investors do not learn from the rate of interest.

3.2 Equilibrium Price Informativeness

The precision of investors' posterior beliefs can be obtained directly from Theorem 1:

Lemma 2. *The precision of investor i's posterior beliefs regarding the stock's payoff is given by:*

$$\mathbb{V}ar\,(\Pi \,|\, \mathcal{F}_i)^{-1} = \tau = \tau_\Pi + \tau_\varepsilon + (\tau_\varepsilon/\gamma)^2\, \tau_{\theta_X|R_f}, \tag{14}$$

where $(\tau_\varepsilon/\gamma)^2\, \tau_{\theta_X|R_f}$ *represents the informativeness of the stock price.*

The posterior precision in our framework has the same form as in Hellwig (1980) and is made up of three components: (i) the precision of the investors' prior beliefs τ_Π, (ii) the precision of their private signal τ_ε, and (iii) the precision of the stock-price signal $(\tau_\varepsilon/\gamma)^2\, \tau_{\theta_X|R_f}$ which is driven by the posterior precision $\tau_{\theta_X|R_f}$ and the signal-to-noise ratio of the stock-price signal $(\tau_\varepsilon/\gamma)$. Consistent with Hellwig (1980), the posterior precision is increasing in the prior precision, the precision of private information, the prior precision of the stock supply, and investors' risk-tolerance.

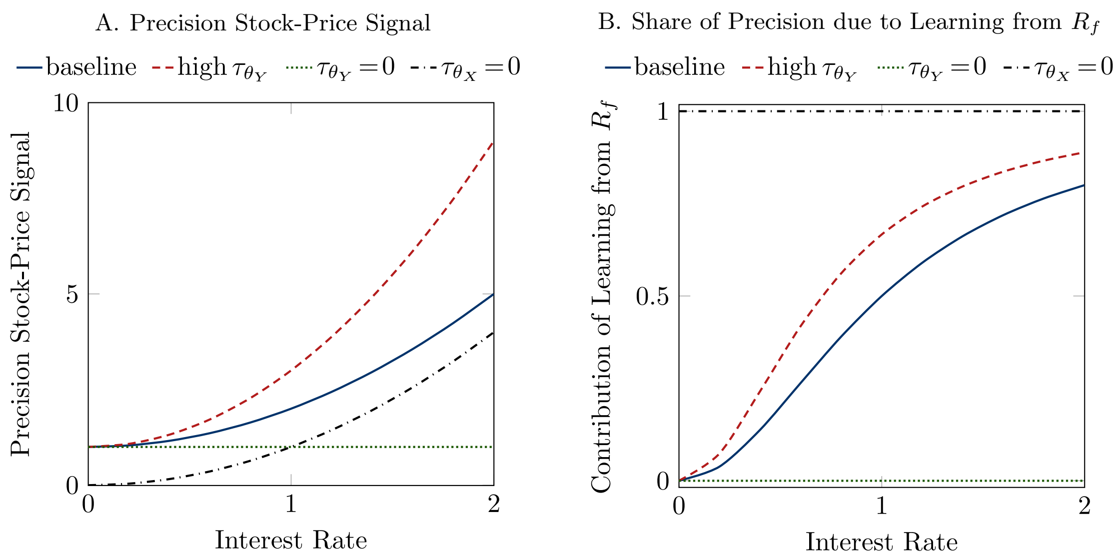

Figure 5: Precision of the Stock-Price Signal (*in the absence of initial consumption*). The figure plots the precision of the stock-price signal, $(\tau_\varepsilon/\gamma)^2\,\tau_{\theta_X|R_f}$, (Panel A) and the share of the stock-price signal's precision that can be attributed to investors' learning from the interest rate (Panel B), as functions of the interest rate R_f—for different levels of the prior precision of the bond supply, τ_{θ_Y}. The graphs are based on the following baseline parameter values: $\gamma = 1$, $\Pi_1 = 1$, $\mu_\Pi = 1$, $\tau_\Pi = 4^2$, $\tau_\epsilon = 0.5^2$, $\mu_{\theta_X} = 1$, $\tau_{\theta_X} = 8^2$, $\mu_{\theta_Y} = 0.5$, and $\tau_{\theta_Y} = 8^2$. High τ_{θ_Y} describes an economy with a higher precision of the bond supply; $\tau_{\theta_Y} = 0$ describes an economy in which investors do not learn from the rate of interest; and $\tau_{\theta_X} = 0$ describes an economy in which the (prior) stock supply is completely uninformative.

However, similar to the equilibrium price function, the posterior precision regarding the stock's payoff (14) differs from Hellwig (1980) along one key dimension: investors' *posterior* precision of the *stock supply*, $\tau_{\theta_X|R_f}$, enters the price-signal component (third term in (14))—instead of the investors' prior precision regarding the stock supply, τ_{θ_X}. As a result, the precision of the stock-price signal and, hence, investors' posterior precision are higher than in Hellwig (1980). This enhanced precision can be entirely attributed to learning from the interest rate, that is, to the information regarding the stock supply which investors obtain from the bond market.[21]

Importantly, the precision of the stock-price signal and, in turn, the posterior precision in (14) depend on R_f. In particular, one of the key prediction of our framework is that the *precision of the stock-price signal is increasing in the (absolute) level of the interest rate.* That is, as discussed above, a higher absolute value of the interest rate allows investors to more precisely infer the stock's supply because it dampens the noise from the bond supply

[21] Specifically, the signal-to-noise ratio of the stock-price signal, τ_ε/γ, is the same as in Hellwig (1980) and unaffected by market-clearing in the bond market.

(see also (11)). Hence, they can extract more information from the stock's price about the stock's payoff. The dependence on the interest rate also implies that, in stark contrast to traditional REE models with Gaussian shocks, the precision of the stock-price signal as well as total posterior precision (τ) depend on the *realization* of the state variables θ_X and θ_Y and, hence, are not known *ex-ante*.

Panel A of Figure 5 illustrates this effect. It shows that the precision of the stock-price signal increases in the (real) interest rate and that this effects is stronger for more precise priors about the bond supply (i.e., higher τ_{θ_Y}) because this allows investors to form more precise posterior beliefs about the stock supply.[22] Panel A of Figure 5 also highlights two interesting limiting cases. First, if the bond supply is uninformative ($\tau_{\theta_Y} = 0$), the precision of the stock signal and, hence, the posterior precision are constant (and the same as in Hellwig 1980). This is because in this case the bond signal cannot be used to form more precise beliefs about the stock's supply; that is, $\tau_{\theta_X|R_f} = \tau_{\theta_X}$. Second, the stock signal provides information about the stock's payoff even if the stock supply is completely diffuse ($\tau_{\theta_X} = 0$). Indeed, in that case, the distribution is no longer diffuse conditional on the interest rate, $\tau_{\theta_X|R_f} > 0$ (provided $\tau_{\theta_Y} > 0$) which, in turn, allows investors to learn about the stock's payoff from the stock's price. Such a situation cannot arise in Hellwig (1980).

Finally, Panel B of Figure 5 reports the share of the stock-price signal's precision that can be attributed to learning from the interest rate (relative to the overall precision of the stock-price signal). It illustrates the importance of learning from the interest rate. As expected, the importance of bond learning increases with the interest rate and the precision of the bond supply because these imply a more precise bond signal. Interestingly, the fraction of price informativeness resulting from bond-market learning is often sizeable and, for some values of the interest rate and bond-supply precision, bond-market learning accounts for the bulk of the precision of the stock-price signal. Naturally, in the two limiting cases, the relative contribution of the bond-market signal is zero ($\tau_{\theta_Y} = 0$) or one ($\tau_{\theta_X} = 0$).

[22] In that regard, the figure is reminiscent of Figure 3 which shows the posterior precision of the stock supply (which is the only component of posterior precision that varies with the interest rate).

4 Rational Expectations Equilibrium with an Endogenous Interest Rate

Having described the key economic mechanism, we now turn initial consumption back on, and study how characteristics of the bond market—namely, the mean and the precision of the bond supply—shape equilibrium asset prices and their informativeness.

4.1 Equilibrium

Investor i now chooses consumption in *both* periods, $C_{i,1}$ and $C_{i,2}$, together with her holdings of the bond and the stock, Y_i and X_i, in order to maximize expected utility (3) subject to the budget constraints (4). Consequently, the investor's optimal demand for the bond, $Y_i = R_f\,(W_{i,1} - X_i P - C_{i,1})$, now also depends on her initial consumption, $C_{i,1}$, which, in turn, depends on the interest rate, the investor's desire to smooth consumption intertemporally, and the speculative profits she expects from trading the stock.

In equilibrium, investors' aggregate income from the stock ($\Pi_1\theta_X$) equals the sum of aggregate consumption and of aggregate (net) saving (θ_Y/R_f), or, formally:

$$0 = \theta_X - \frac{\theta_Y}{R_f\,\Pi_1} - \frac{1}{\Pi_1}\int_0^1 C_{i,1}\,di. \tag{15}$$

Again, the market-clearing condition (15) links together the supplies in the bond and stock markets and, hence, is a noisy signal about the stock supply θ_X, with noise stemming from the bond supply θ_Y. Thus, in line with the economic mechanism described in the preceding section, investors use information revealed by the bond market to update their beliefs about the stock's supply. Note, however, that, due to investors' intertemporal consumption choices, the market-clearing condition now also involves investors' time-1 aggregate consumption (which was absent from the clearing condition without initial consumption (11)). As a result, that condition is no longer linear in the state variables and, hence, the inference

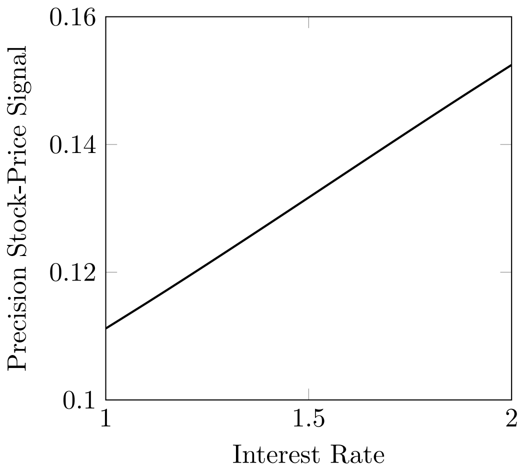

Figure 6: Precision of the Stock-Price Signal (*in the presence of initial consumption*). The figure plots the precision of the stock-price signal as a function of the interest rate, R_f. The precision of the stock-price signal is measured as the square root of the difference between the unconditional variance of the payout and its variance conditional on the stock price (and the interest rate): $\sqrt{\mathbb{V}\mathrm{ar}(\Pi) - \mathbb{V}\mathrm{ar}(\Pi \,|\, R_f, P)}$. The graph is based on the following parameter values: $\beta = 1$, $\gamma = 1$, $\Pi_1 = 1$, $\mu_\Pi = 1$, $\tau_\Pi = 4^2$, $\tau_\epsilon = 0.5^2$, $\mu_{\theta_X} = 1$, $\tau_{\theta_X} = 8^2$, $\mu_{\theta_Y} = 0.5$, $\tau_{\theta_Y} = 8^2$, and drawn for realizations of the payout, Π, and the bond supply, θ_Y, equal to their expectation.

problem involves non-linear functions, making it impossible to identify the equilibrium in closed-form.[23,24]

Equation (15), linking the assets' supplies, is agian denominated in units of the good, implying that a higher IR dampens the bond noise and improves the signal-to-noise ratio. This is illustrated in Figure 6.[25] Interestingly, this also implies that investors' posterior precision is stochastic and, hence, *ex-ante* unknown—a feature that could, in a model with endogenous information choice (à la Verrecchia 1982), deliver additional, rich insights regarding investors' *demand* for information.

4.2 Price Informativeness

In a first step, we document how characteristics of the bond market affect the informativeness of the stock price. We define price informativeness, PI, as the square root of the

[23]For instance, even in the absence of initial consumption, aggregate expected trading profits depend on the aggregate squared Sharpe ratio, $\int \frac{\left(\mathbb{E}[\Pi \,|\, \mathcal{F}_i] - R_f\, P\right)^2}{\gamma\, \mathbb{V}\mathrm{ar}(\Pi \,|\, \mathcal{F}_i)} di$, which is a non-linear function of the state variables.

[24]We discuss the (technical) details of our numerical solution approach in Appendix D.

[25]The corresponding figure without initial consumption can be found in Panel A of Figure 5.

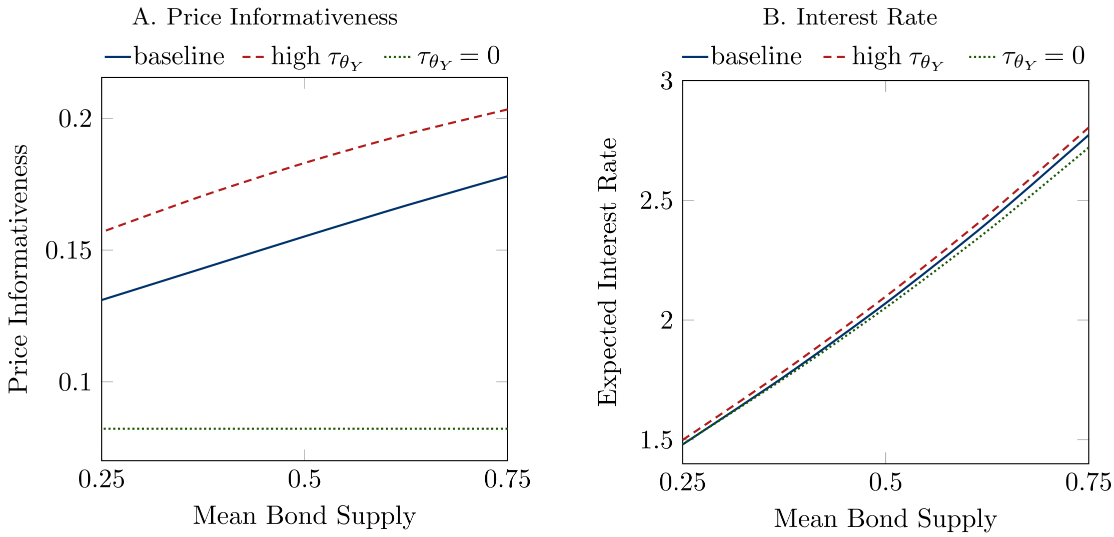

Figure 7: Price Informativeness and Interest Rate (*in the presence of initial consumption*). The figure plots price informativeness (Panel A) and the expected interest rate (Panel B), as functions of the mean bond supply, μ_{θ_Y}—for three different values for the prior precision of the bond supply, τ_{θ_Y}. Price informativeness, PI, is calculated as in Equation (16). Panel B reports the expected interest rate (averaging over all realizations of the state variables). The graphs are based on the following baseline parameter values: $\beta = 1$, $\gamma = 1$, $\Pi_1 = 1$, $\mu_\Pi = 1$, $\tau_\Pi = 4^2$, $\tau_\epsilon = 0.5^2$, $\mu_{\theta_X} = 1$, $\tau_{\theta_X} = 8^2$, and $\tau_{\theta_Y} = 8^2$. High τ_{θ_Y} describes an economy with a higher precision of the bond supply and $\tau_{\theta_Y} = 0$ describes an economy in which investors do not learn from the rate of interest.

unconditional variance of the predictable component of the payoff Π conditional on prices:

$$PI^2 = \mathbb{V}\text{ar}\big(\mathbb{E}\left[\Pi \,|\, R_f, P\right]\big). \tag{16}$$

This is the natural one-stock counterpart to the price-informativeness measure used in our empirical analyses.[26]

Panel A shows that price informativeness is increasing in the mean bond supply. This effect is driven by the corresponding increase of the rate of interest in the mean bond supply μ_{θ_Y} (Panel B of Figure 7), as a larger bond supply requires a lower bond price for the market to clear.[27] As discussed above, indeed, an increase in the interest rate dampens the noise

[26]Our results are robust to defining price informativeness as the expected precision of the stock-price signal (in excess of prior precision): $\mathbb{E}\left[1/\mathbb{V}\text{ar}(\Pi|R_f, P) - \tau_\Pi\right]$. Moreover, in Appendix E, we demonstrate—using a two-stock extension of our model—that our theoretical results are robust to using the *cross-sectional variance* of the predictable component of firms' payoffs—as in the empirical measure (2).

[27]It is straightforward to show that the (gross) interest rate is always positive here (in contrast to the setting without initial consumption). Intuitively, any investor's first-order condition for optimal consumption implies that the equilibrium interest rate is pinned down by the marginal rate of substitution across periods:

$$R_f = \frac{1}{\beta} \frac{\exp(-\gamma C_{i,1})}{\mathbb{E}\big[\exp(-\gamma C_{i,2}) \,|\, \mathcal{F}_i\big]} > 0.$$

in the bond-market signal. Hence, it allows investors to form more precise posterior beliefs about the stock's supply and to better infer the stock's payout from its price. As a result, the fraction of price informativeness attributable to bond-market learning also increases in mean bond supply (not shown). Moreover, an increase in the prior precision of the bond supply, τ_{θ_Y}, strengthens the effect of the mean bond supply. Indeed, only if the bond market is uninformative ($\tau_{\theta_Y} = 0$), is this effect absent and price informativeness independent of the mean bond supply (as in "standard" REE models, such as Hellwig 1980).[28]

4.3 Consumption Choices

Naturally, changes in the interest rate as well as in price informativeness have a concurrent impact on investors' consumption choices (which, in turn, "feed back" into the equilibrium interest rate and price informativeness). This effect is illustrated in Figure 8 which depicts investors' consumption choices in both periods as a function of the mean bond supply. While consumption in period 1 is typically declining in the mean bond supply, consumption in period 2 tends to increase. This is the result of four effects, with only the last two related to learning from interest rates. First, a higher rate of interest increases the price of period-1 consumption relative to period-2 consumption and so shifts consumption from period 1 to period 2 (substitution effect). Second, a higher interest rate makes investors "richer" and so increases consumption in both periods (income effect). Both effects push up consumption in period 2, but operate in opposite direction for period-1 consumption. For usual levels of risk-aversion, the substitution effect dominates and, hence, consumption in period 1 declines (as can be seen for the case of an uninformative bond supply: $\tau_{\theta_Y} = 0$).

Investors' learning from the bond market generates two further effects—provided the bond-market is informative ($\tau_{\theta_Y} > 0$). On the one hand, higher price informativeness reduces investors' expected trading profits and, in turn, their consumption in both periods. On the other hand, by reducing uncertainty, it diminishes precautionary savings and, thus, increases consumption in period 1 which explains the flattening in period-1 consumption

[28] Moreover, as pointed out earlier, provided $\tau_{\theta_Y} > 0$, the stock's price can convey information even if the stock's supply is uninformative ($\tau_{\theta_X} = 0$) because, conditional on the rate of interest, it is informative.

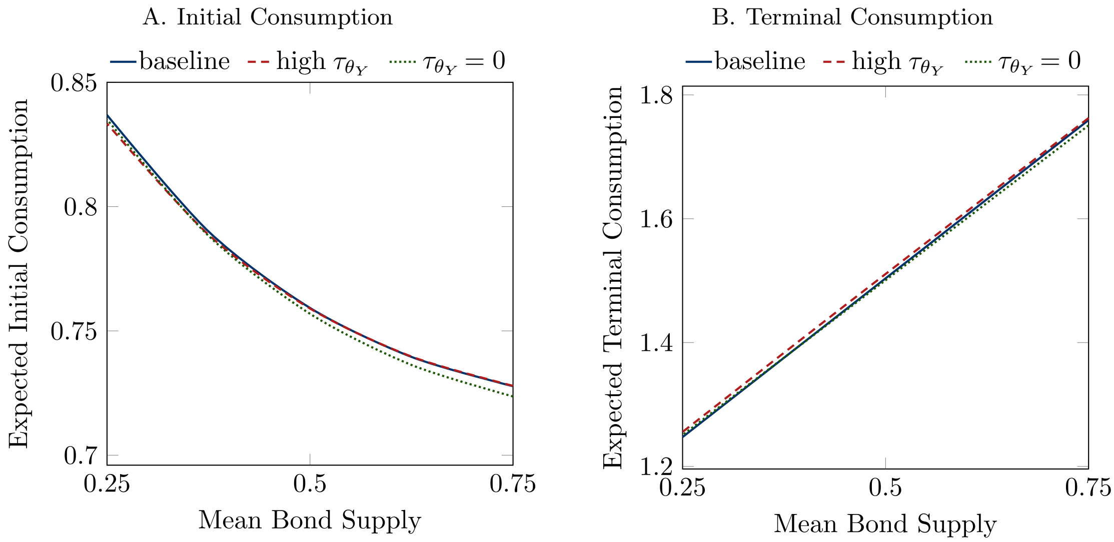

Figure 8: Consumption Choices (*in the presence of initial consumption*). The figure plots investors' expected initial (period-1) consumption (Panel A) and their expected terminal (period-2) consumption (Panel B), as functions of the mean bond supply, μ_{θ_Y}—for three different values for the prior precision of the bond supply, τ_{θ_Y}. We report the unconditional expectation of both quantities, averaging over all realizations of the state variables. The graphs are based on the following baseline parameter values: $\beta = 1$, $\gamma = 1$, $\Pi_1 = 1$, $\mu_\Pi = 1$, $\tau_\Pi = 4^2$, $\tau_\epsilon = 0.5^2$, $\mu_{\theta_X} = 1$, $\tau_{\theta_X} = 8^2$, and $\tau_{\theta_Y} = 8^2$. High τ_{θ_Y} describes an economy with a higher precision of the bond supply and $\tau_{\theta_Y} = 0$ describes an economy in which investors do not learn from the rate of interest.

for high levesl of mean bond supply—compared to the case with an uninformative interest rate ($\tau_{\theta_Y} = 0$).

4.4 Asset Prices

The changes in the interest rate, investors' consumption choices, and price informativeness (described above) also affect the equilibrium stock price and the corresponding return moments. As shown in Panel A of Figure 9, the price ratio, $R_f P$, increases in the mean bond supply provided the bond market is informative ($\tau_{\theta_Y} > 0$). Specifically, as the supply of the bond increases, the informativeness of the stock price rises. This, in turn, reduces the risk borne by investors and, consequently, the price discount required by risk-averse investors, pushing up the price ratio.[29] By the same account, the stock's expected excess return is declining in the mean bond supply (Panel B). Higher price informativeness also implies that the stock's price tracks its payoff more closely, thereby reducing return volatility (Panel C).

[29]Accordingly, the price ratio is always higher for the case of an informative bond supply than for that of an uninformative supply.

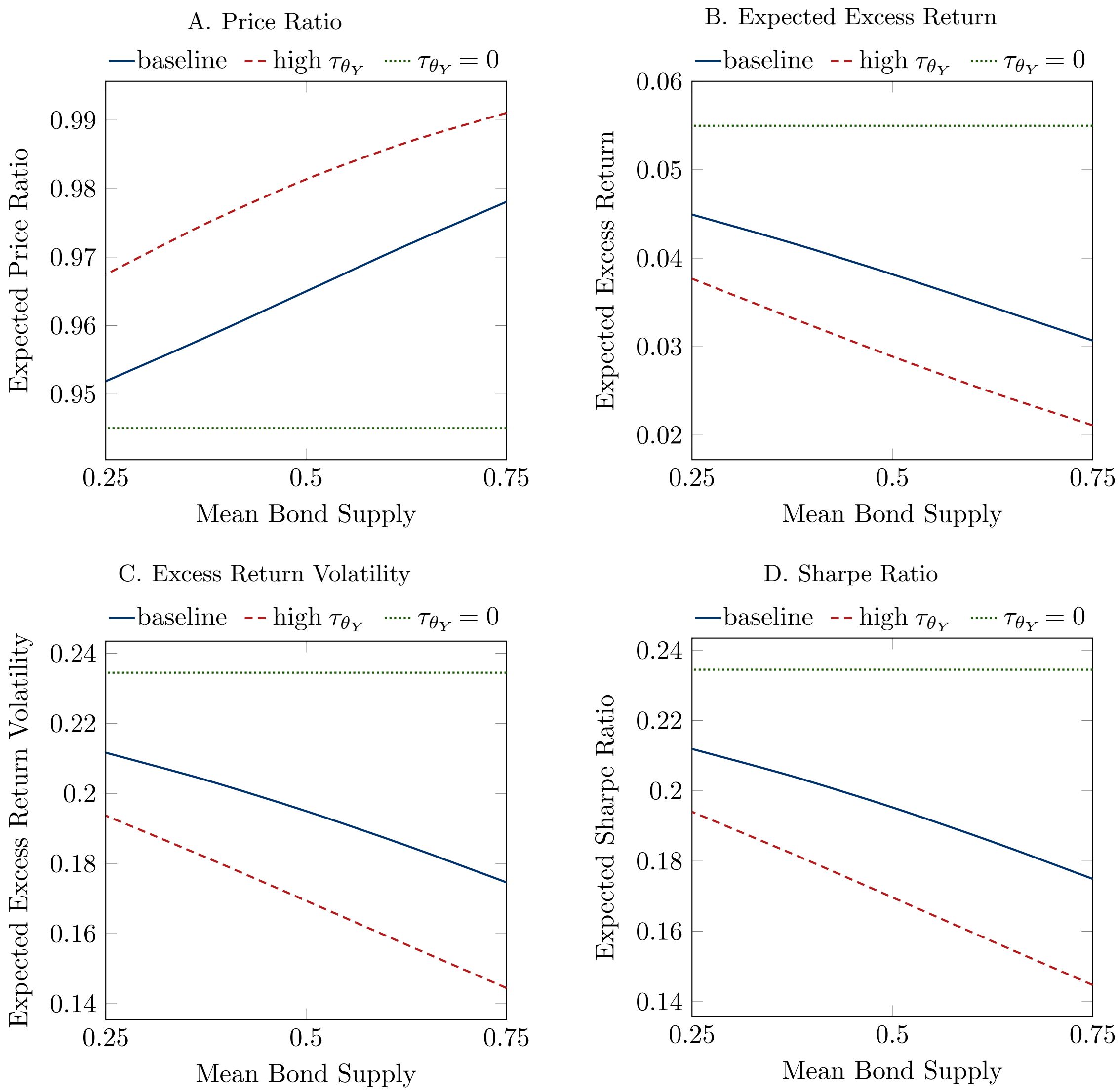

Figure 9: Stock-Price Moments (*in the presence of initial consumption*). The figure plots the expected price ratio (Panel A), the expected excess return (Panel B), the expected excess-return volatility (Panel C), and the Sharpe ratio (Panel D), as functions of the mean bond supply, μ_{θ_Y}—for three different values for the prior precision of the bond supply, τ_{θ_Y}. We report the unconditional expectation of all quantities, averaging over all realizations of the state variables. The graphs are based on the following baseline parameter values: $\beta = 1$, $\gamma = 1$, $\Pi_1 = 1$, $\mu_\Pi = 1$, $\tau_\Pi = 4^2$, $\tau_\epsilon = 0.5^2$, $\mu_{\theta_X} = 1$, $\tau_{\theta_X} = 8^2$, and $\tau_{\theta_Y} = 8^2$. High τ_{θ_Y} describes an economy with a higher precision of the bond supply and $\tau_{\theta_Y} = 0$ describes an economy in which investors do not learn from the rate of interest.

Finally, the Sharpe ratio (price of risk) declines with the mean bond supply (Panel D), indicating that return volatility decreases more sharply than does the expected excess return. That is, because uncertainty about the stock's payoff declines, investors' demand goes up, so that—for markets to clear—the Sharpe ratio (capturing the equilibrium incentive to buy the stock) declines.

A higher precision of the bond supply strengthens all these effects (Panels A to D). In contrast, in the case of an uninformative bond market ($\tau_{\theta_Y} = 0$), the price ratio, expected excess return, return volatility and Sharpe ratio are all unrelated to the mean bond supply and, hence, to the rate of interest (as in traditional REE models).

To study how learning from the interest rate affects the *co-movement* of stocks, we now extend our main framework to the case of multiple stocks. Specifically, we assume that there exist two stocks, $k \in \{1, 2\}$, with terminal payoffs, $\Pi^{(k)}$, and supplies, $\theta_X^{(k)}$, drawn independently from identical distributions (and initial, exogenous payoffs $\Pi_1^{(k)} > 0$). Investors receive private signals about both stocks' payoffs. Otherwise, the economic framework introduced in Section 2 remains unchanged; in particular, investors consume in both periods and the rate of interest is determined endogenously.[30]

The market-clearing condition for the bond now links not only the bond supply with each stock's supply but also the two stocks' supplies with each other. Specifically, learning from the bond market creates a negative correlation between an investors' beliefs regarding the two stocks' supplies. To see why, note that aggregate income is now consists of income income from stock 1 and income from stock 2, yielding the following two-stock counterpart to the one-stock bond-market clearing condition (15):

$$0 = \Pi_1^{(1)}\, \theta_X^{(1)} + \Pi_1^{(2)}\, \theta_X^{(2)} - \frac{\theta_Y}{R_f} - \int_0^1 C_{i,1}\, di. \tag{17}$$

In words, market clearing in the bond market constrains the (weighted) *sum* of the two stocks' supplies. Hence, conditional on bond supply and aggregate consumption, an investor who assigns a higher value to the one of the stock's supply rationally assigns a lower value to the supply of the other stock. This naturally induces a negative correlation between her beliefs regarding the two stocks' payoffs which, in turn, lowers the correlation of the two stocks' excess returns. Crucially, this effect strengthens with the precision of the bond-market signal. Hence, the correlation of the excess returns declines (or put differently, their dispersion rises) in the interest rate, or, equivalently, in the mean bond supply (provided

[30] The technical details of the two-stock model are relegated to Appendix E.

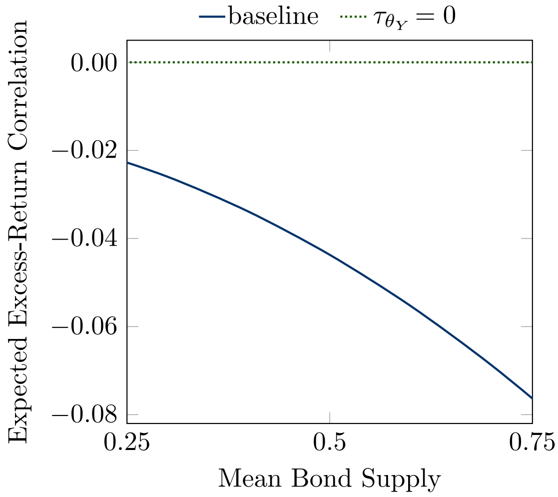

Figure 10: Excess-Return Correlation (*in the presence of initial consumption and with two stocks*). The figure plots the expected excess-return correlation of two (symmetric) stocks, as a function of the mean bond supply, μ_{θ_Y}—for three different values for the prior precision of the bond supply, τ_{θ_Y}. Expected correlation is calculated as the expectation of the conditional correlation between the two stocks' returns in excess of the interest rate conditional on prices (averaging over all realizations of the state variables). The graph is based on the two-stock extension presented in detail in Appendix E and on the following parameter values: $\beta = 1$, $\gamma = 1$, $\Pi_1^{(k)} = 1/2$, $\mu_\Pi = 1$, $\tau_\Pi = 4^2$, $\tau_\epsilon = 0.5^2$, $\mu_{\theta_X} = 1$, $\tau_{\theta_X} = 8^2$, and $\tau_{\theta_Y} = 8^2$. High τ_{θ_Y} describes an economy with a higher precision of the bond supply and $\tau_{\theta_Y} = 0$ describes an economy in which investors do not learn from the rate of interest.

$\tau_{\theta_Y} > 0$). This is illustrated in Figure 10.[31] Notably, the correlation of the two stocks' excess returns is non-zero despite their payoffs and supplies being independent—in stark contract to Admati (1985).

Overall, these results highlight that changes in bond-market characteristics have important implications for price informativeness and asset prices. In particular, variations in the mean and variance of the bond supply influence the stock market not only through their traditional impact on discount rates but also through their impact on the informativeness of interest rates.

[31] For ease of exposition, we have assumed independent payoffs and supplies. As a result, the conditional correlation of the two stocks' excess returns is zero without learning from the interest rate ($\tau_{\theta_Y} = 0$). To accommodate a positive correlation between the two stocks (as it is typically the case empirically), one could simply work with positively correlated payoffs.

5 The Real Effects of Learning from the Bond Market

To highlight how bond-market characteristics—through their impact on the informativeness of the stock price—affect real (capital-allocation) efficiency, we now allow for real-investment decisions.

5.1 Economic Framework

The model is a straightforward extension of the framework introduced in Section 2 with intertemporal consumption choices and an endogenous rate of interest. The key difference is that output is now endogenous and produced by a representative firm according to a linear ('AK') production technology. The firm is endowed in period 1 with assets in place K_1 and its fundamental value, v, is modelled as in standard q-theory (Hayashi 1982):

$$v(a, I) \equiv (K_1 - I) + (1 + a)\big((1 - \delta)K_1 + I\big) - \frac{c}{2\,K_1}\,I^2, \tag{18}$$

where a denotes period-2 (net) productivity, δ denotes the rate of depreciation, and I denotes the firm's real investment which is subject to quadratic adjustment costs $(c/2K_1)\,I^2$, where $c > 0$. For ease of exposition, period-1 productivity is normalized to one, so that period-1 payout to investors is simply given by $\Pi_1 = K_1 - I$. Period-2 productivity, a, is normally distributed with mean μ_a and precision τ_a: $a \sim \mathcal{N}(\mu_a, 1/\tau_a)$.

Investors receive an unbiased private signal about productivity, a, with precision τ_ε. By trading the stock—which is modelled as a claim to a final payout $\Pi = (1 + a)\big((1 - \delta)K_1 + I\big) - (c/2K_1)\,I^2$—investors impound their private information into its price, from which the manager can learn about productivity a. This creates a *feedback effect* from financial markets to real investment decisions by which price informativeness affects firm value and real efficiency.[32]

[32] Bond, Edmans, and Goldstein (2012) provide an excellent survey on feedback effects from financial markets to the real economy. For empirical evidence on the importance of feedback effects confer Bakke and Whited (2010), Durnev, Morck, and Yeung (2004), Luo (2005), Chen, Goldstein, and Jiang (2007), Foucault and Frésard (2014), Edmans, Goldstein, and Jiang (2015), and Dessaint, Foucault, Frésard, and Matray (2018).

Specifically, we assume—for simplicity—that the firm's manager has no private information regarding a.[33] She chooses the optimal investment, I, in order to maximize the expected firm value under her information set, $\mathbb{E}\left[v(a,I)\,|\,R_f,P\right]$, which yields the standard q-theory investment equation (Tobin 1969):

$$\frac{I}{K_1} = \frac{\mathbb{E}\left[a\,|\,P,R_f\right]}{c}. \tag{19}$$

In words, the investment rate, I/K_1, is proportional to the manager's conditional expectation of productivity a. Note, also that this production economy nests the endowment economy discussed in the preceding section: If the adjustment cost c is infinite, then investment, I, is zero; rendering period-2 output exogenous (equal to $(1+a)K_1$).

The equilibrium is characterized by investors' optimality conditions (for consumption and portfolio choice), the market-clearing conditions (identical to (5)), and—new to this setup—the optimal investment condition (19). Again, we determine the equilibrium numerically.

5.2 Bond-Market Characteristics and Real Efficiency

As in the preceding sections, investors use the information revealed by the interest rate to form posterior beliefs about the stock's payoff. Accordingly, as shown in Panel A of Figure 11, price informativeness increases in the mean bond supply μ_{θ_Y}—provided the bond supply is informative (i.e., $\tau_{\theta_Y} > 0$)—a consequence of the ensuing higher interest rate and, hence, of the more precise bond-market signal.

Most importantly, the firm manager too uses the information revealed by the interest rate to improve her forecast of the productivity shock, a. As a result, her real-investment choice, I, is more closely aligned with productivity, leading to more efficient investment decisions. Put differently, the firm manager can better differentiate high-productivity states

[33] In particular, in our single-stock economy, the firm and a can be interpreted, respectively, as the aggregate economy and *aggregate* productivity—about which the manager need not be privately informed.

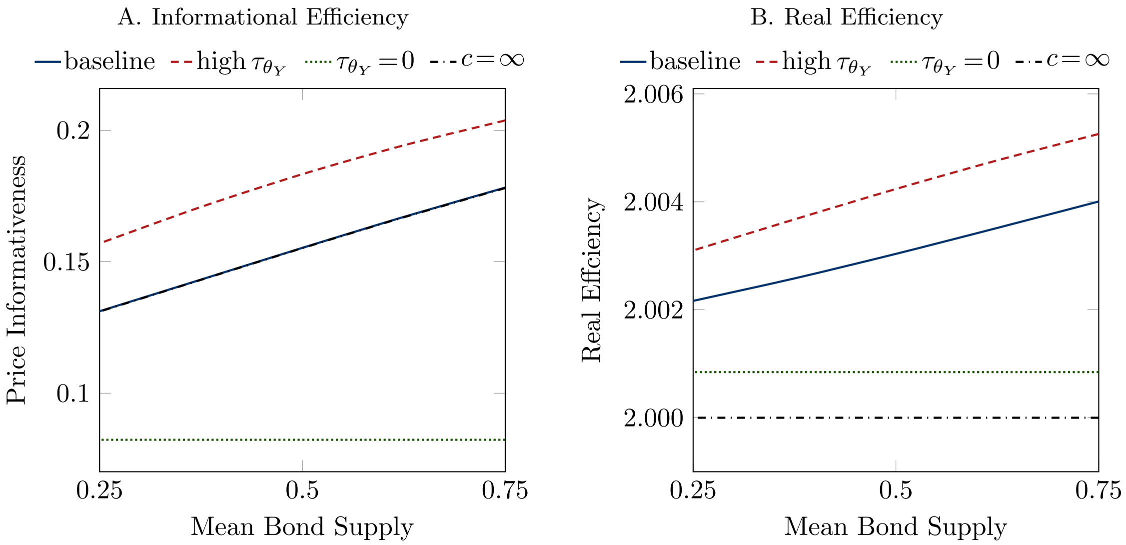

Figure 11: Informational and Real Efficiency (*in the presence of initial consumption and endogenous output*). The figure plots price informativeness (Panel A) and real efficiency (Panel B), as functions of the mean bond supply, μ_{θ_Y}—for three different values for the prior precision of the bond supply, τ_{θ_Y}. Price informativeness, PI, and real efficiency, $\mathcal{E}$, are calculated as in Equations (16) and (21), respectively. The graphs are based on the following baseline parameter values: $K_1 = 1$, $c = 4$, $\delta = 0$, $\beta = 1$, $\gamma = 1$, $\mu_a = 0$, $\tau_a = 4^2$, $\tau_\epsilon = 0.5^2$, $\mu_{\theta_X} = 1$, $\tau_{\theta_X} = 8^2$, and $\tau_{\theta_Y} = 8^2$. High τ_{θ_Y} describes an economy with a higher precision of the bond supply; $\tau_{\theta_Y} = 0$ describes an economy in which investors do not learn from the rate of interest; and $c = \infty$ describes an economy in which real investment is zero and, hence, output is exogenous.

(in which she should invest more) from low-productivity states (in which she should invest less).[34]

Formally, real efficiency in the economy can be measured as expected (normalized) total output:

$$\mathcal{E} = \frac{\mathbb{E}\left[(K_1 - I) + \mathbb{E}\left[(1+a)\left((1-\delta)K_1 + I\right) - \frac{c}{2K_1} I^2 \,\middle|\, P, R_f\right]\right]}{K_1} \tag{20}$$

$$= 2 - \delta + \mu_a\left(1 + \frac{\mu_a}{2c}\right) + \frac{1}{2c}\underbrace{\mathbb{V}ar\left(\mathbb{E}\left[a \,|\, P, R_f\right]\right)}_{=\mathbb{V}\text{ar}(a) - \mathbb{E}\left[\mathbb{V}\text{ar}\left(a|P,R_f\right)\right]}. \tag{21}$$

As (21) shows, real efficiency is increasing in the difference between the prior and (expected) posterior variances, which captures the additional information provided by the price system. Hence, real efficiency is increasing in price informativeness or, equivalently, in the mean bond

[34] This implies a higher volatility of real investment, compared to the case of an uninformative bond supply ($\tau_{\theta_Y} = 0$) in which price informativeness is lower.

supply. This is illustrated in Panel B of Figure 11. Naturally, the increase in real efficiency is stronger when the bond supply is more informative (high τ_{θ_Y}).

Importantly, a higher real efficiency does not result from a higher *level* of real investment. In fact, expected investment, $\mathbb{E}[I] = (aK_1)/c$, is, by design, constant. Instead, the positive effect of the mean bond supply (or, equivalently, of the interest rate) on real efficiency results from more *efficient* real-investment decisions.

In summary, this section highlights how characteristics of the bond market, namely the mean bond supply and its precision, affect allocative efficiency and, hence, aggregate welfare—through a novel price-informativeness channel.

6 The Impact of Monetary and Fiscal Policies on Informational Efficiency

Finally, we also study how government policies affecting bond supply—specifically, monetary and fiscal policies—influence informational efficiency. For that purpose, we extend the model described in Section 2 by allowing for government spending and taxation, as well as money. As a result, we now distinguish between real variables and nominal variables. This offers the additional benefit of "closing" the model, that is, of ensuring that any changes in the bond supply are matched with offsetting changes in either government spending, seignorage, or tax proceeds.

6.1 Economic Framework

As before, the population consists of investors and noise traders. Whereas investors are represented as optimizing agents, the behaviour of noise traders is not explicitly modelled and characterized instead by their residual (random) demands for assets. In addition, there now also exists a government. Our model of the *government* is purposely simple: it is a neoclassical model, in which money is neutral (so real variables are determined independently of nominal variables), Ricardian equivalence holds (so agents internalize the government's budget constraints when making decisions), and government policies are exogenous and credible. These policies satisfy the government's budget constraints, which, in our 2-period economy, implies that bonds and money issued in period 1 are redeemed in full in period 2.[35]

The government consumes goods in periods $t = 1$ and $t = 2$, and finances its spending with a mix of taxes, debt and money. It collects T_{it} (goods) from investor i through lump-sum taxes, and T_t in aggregate. It issues real riskfree bonds in period 1 that pay out one unit of the good in period 2.[36] These bonds can be interpreted as those we analysed in the previous sections of the paper. The government also prints money in period 1, which it redeems in period 2. We assume that, in period 1, the government commits credibly to target levels for inflation (i.e., the period-2 good's price) and for tax proceeds (T_{2i} for every agent i).

Because money is dominated as a store of value (to the extent that bonds pay strictly positive nominal interest), we introduce a benefit of holding money by assuming that agents derive utility from the quantity of real money balances they hold (which equals the number of goods their stock of money could purchase in period 1).[37] Specifically, investor i has preferences of the following type:

$$U_i(C_{i,1}, C_{i,2}) = -\frac{1}{\gamma}\exp\big(-\gamma\, C_{i,1}\big) + \beta\,\mathbb{E}\left[-\frac{1}{\gamma}\exp\big(-\gamma\, C_{i,2}\big)\,\middle|\,\mathcal{F}_i\right] + \omega\, v\left(\frac{M_i}{P_1^G}\right), \tag{22}$$

where P_t^G denotes the price of the good in period t, M_i denotes money holding, v is an increasing and concave function of agent i's real money balance in period 1 (M_i/P_1^G) and ω denotes the "weight" of money-balance utility component. The objective of each investor i is to maximize expected utility (22) subject to the following budget equations:

$$C_{i,1} + X_i\, P + Y_i\, R_f^{-1} + \frac{M_i}{P_1^G} = W_{i,1} - T_{i,1}, \quad \text{and} \quad C_{i,2} = X_i\,\Pi + Y_i + \frac{M_i}{P_2^G} - T_{i,2}. \tag{23}$$

[35]A straightforward extension of the model is to assume these policies are chosen by the government to maximise a social-welfare function.

[36]Default on government debt does not occur because, under CARA utility, there is no limit to how much taxes can be collected from agents (since their consumption can be negative).

[37]This is a commonly used short-cut to model the usefulness of money as a medium of exchange. It captures the notion that, the higher the purchasing power of an agent's money holdings, the lower is the disutility cost associated with exchange, which results in higher overall utility.

The budget equations are expressed in *real terms* and differ from those in (4) only in that investors now also hold money (M_i) and must pay taxes ($T_{i,1}$ and $T_{i,2}$).

In addition to the stock and bond supplies, we assume that the supply of money is noisy because with three price signals, three sources of noise are needed to prevent prices from being perfectly revealing.[38] We denote θ_M the residual random supply of money, that is, the supply of money minus noise traders' demand; with $\theta_M \sim \mathcal{N}(\mu_{\theta_M}, 1/\tau_{\theta_M})$, where μ_{θ_M} and τ_{θ_M} denote the prior mean and precision of money supply. Moreover, θ_M is uncorrelated with the other supply shocks, θ_X, θ_Y, and with the stock's payoff, Π.

The equilibrium is defined as in Section 2, with the exception that investors, in addition to consumption $\{C_{i,1}, C_{i,2}\}$ and portfolio holdings $\{X_i, Y_i\}$, now also choose their money holdings $\{M_i\}$. Correspondingly, in addition to the bond and stock markets (5), the money market clears, that is, $\int M_i di = \theta_M$.[39] Also, it is important to point out that, in equilibrium, the price of the good now also serves as a signal (as do the bond and stock prices). This is because the good no longer serves as a numéraire; money does. As a result, investor i's information set is given by $\mathcal{F}_i = \{S_i, P, R_f, P_1^G\}$.

6.2 Equilibrium

In equilibrium, the precision of the stock-price signal is increasing in both the real interest rate and the good's price (Figure 12). As discussed in the preceding sections, a higher interest rate improves the precision of the bond signal and, hence, enhances how much information investors can extract from the stock price.

More novel is the positive relation between the good's price (rate of inflation) and the precision of the stock-price signal. Again it is the result of the good's price conveying information: in equilibrium, the good's price is correlated with the supply of the stock through

[38] Because Ricardian Equivalence holds in our economy, the noise that ultimately blurs prices is government consumption regardless of how it is financed.

[39] By Walras' law, clearing in the bond, the stock and the money markets guarantees clearing in the goods markets. Specifically, aggregating rational investors' budget constraints yields $\int C_{i,1} di + \left(T_1 + \frac{\theta_Y}{R_f} + \frac{\theta_M}{P_1^G}\right) = \Pi_1 \theta_X$ in period 1 and $\int C_{i,2} di + \left(T_2 + \theta_Y + \frac{\theta_M}{P_2^G}\right) = \Pi\, \theta_X$ in period 2. Intuitively, the terms in brackets on the left-hand side of each equation represent the consumption of the government which, together with investors' consumption, equals the aggregate supply of the good, displayed on the right-hand side of the equations.

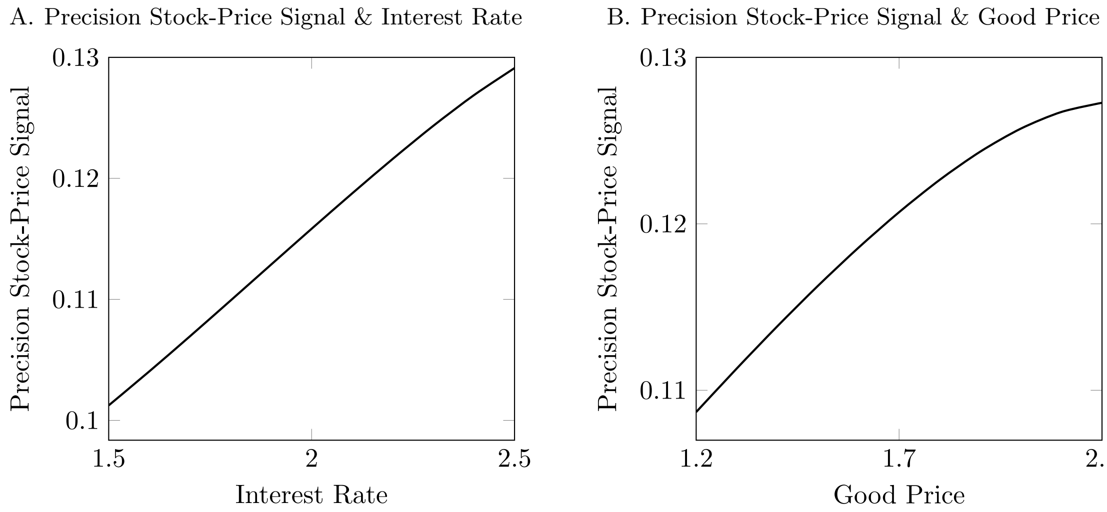

Figure 12: Precision of the Stock-Price Signal (*in the presence of government policies*). The figure plots the precision of the stock-price signal conditional on the interest rate, R_f (Panel A) and conditional on the period-1 good price, P_1^G (Panel B). The precision of the stock-price signal is measured as the square root of the difference between the unconditional variance of the payout and its variance conditional on the prices of the assets and the good: $\sqrt{\mathbb{V}\mathrm{ar}(\Pi) - \mathbb{V}\mathrm{ar}(\Pi \,|\, R_f, P, P_1^G)}$. The graph is based on the following parameter values: $\omega = 0.1$, $v(m) = -\exp(-m)$, $T_{i,t} = 0$, $\beta = 1$, $\gamma = 1$, $\Pi_1 = 1$, $\mu_\Pi = 1$, $\tau_\Pi = 4^2$, $\tau_\epsilon = 0.5^2$, $\mu_{\theta_X} = 1$, $\tau_{\theta_X} = 8^2$, $\mu_{\theta_Y} = 0.5$, $\tau_{\theta_Y} = 8^2$, $\mu_{\theta_M} = 0.5$, and $\tau_{\theta_M} = 8^2\omega^{-3}$, and drawn for realizations of the payout, Π, the bond supply, θ_Y, and the money supply, θ_M equal to their expectation.

the economy's aggregate resource constraint, and so is informative about the stock supply; thus it allows to extract more information about the stock payoff from the stock price, just as the interest rate does. Moreover, a higher good's price conveys more information. To see why, assume, for ease of exposition, that investors consume solely on the terminal date (no initial consumption) and that the government funds itself exclusively by seignorage (no taxes nor bonds). In equilibrium then, aggregate stock income ($\Pi_1\theta_X$) equals aggregate money balance (θ_M/P_1^G), or, formally:

$$0 = \theta_X - \frac{\theta_M}{P_1^G\,\Pi_1}. \tag{24}$$

This equation, which determines the good's price, can be viewed as the counterpart of Equation (11) which determined the interest rate in the absence of initial consumption, money, and taxes. It also serves as a signal about the stock supply θ_X with noise $\theta_M/(\Pi_1\, P_1^G)$. Importantly, a higher good's price scales down the impact of money market noise, making

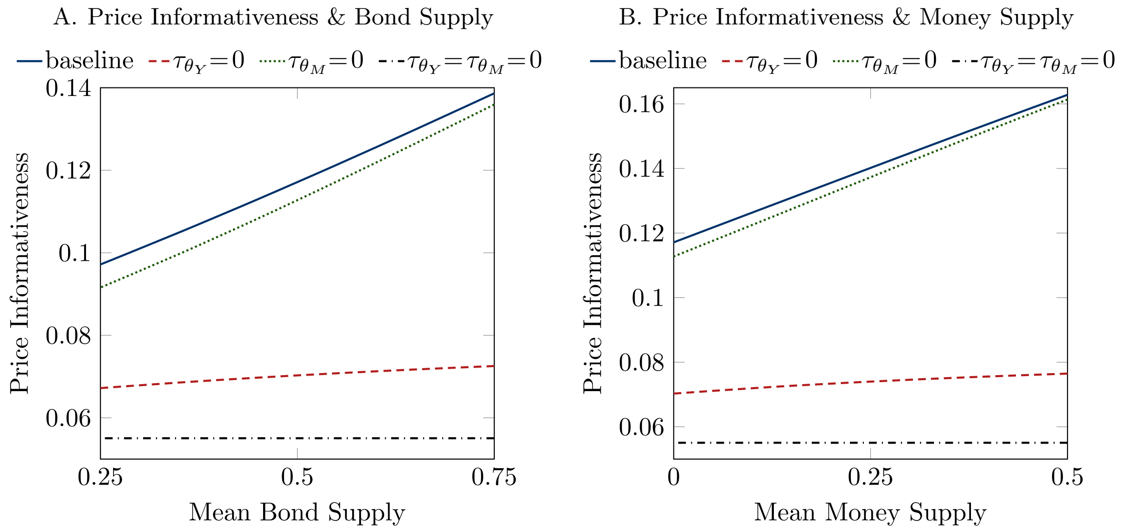

Figure 13: Price Informativeness (*in the presence of government policies*). The figure plots price informativeness as a function of the mean bond supply μ_{θ_Y} (Panel A) and as a function of the mean money supply μ_{θ_M} (Panel B)—for different values of the prior precision of the bond supply τ_{θ_Y} and of the prior precision of the money supply τ_{θ_M}. Price informativeness, PI, is calculated as in Equation (16). The graphs are based on the following baseline parameter values: $\omega = 0.1$, $v(m) = -\exp(-m)$, $T_{i,t} = 0$, $\beta = 1$, $\gamma = 1$, $\Pi_1 = 1$, $\mu_\Pi = 1$, $\tau_\Pi = 4^2$, $\tau_\epsilon = 0.5^2$, $\mu_{\theta_X} = 1$, $\tau_{\theta_X} = 8^2$, $\mu_{\theta_Y} = 0.5$, $\tau_{\theta_Y} = 8^2$, $\mu_{\theta_M} = 0.5$, and $\tau_{\theta_M} = 8^2\omega^{-3}$. $\tau_{\theta_Y} = 0$ describes an economy in which investors do not learn from the rate of interest; $\tau_{\theta_M} = 0$ describes an economy in which investors do not learn from the good's price; and $\tau_{\theta_Y} = 0, \tau_{\theta_M} = 0$ describes an economy in which investors do neither learn from the rate of interest nor the good's price.

it a more precise signal. Intuitively, a higher good's price reduces the value of real money balances, in the same way that the real interest rate scales down bond-market noise.

6.3 The Impact of Monetary and Fiscal Policies on Informational Efficiency

We think of a government policy as consisting of the moments of the bond and money supplies. More precisely, these are the mean and precision of the residual supplies, i.e., of supplies net of noise traders' demands. The mean of the bond and money supplies represent, respectively, the expected levels of government debt and money (e.g., the debt-to-GDP ratio and M2 Money Stock, as in our empirical analysis). Their precisions can be interpreted as the transparency of the government's policy. That is, the government communicates to investors a range of values (in fact, a variance in our setup) for these supplies, with a narrower range allowing investors to know with greater confidence what these values actually are. Thus, a narrower range corresponds to a more transparent policy. Note that, here, government policies are exogenous, and accordingly, do not convey any information to investors. Rather, our focus is on these policies' effect on the public's (as well as the government's own) ability to learn about economic fundamentals from asset prices.[40]

The effect of the mean bond supply is consistent with our prior results, that is, a larger mean bond supply pushes bond prices down and interest rates up. But the presence of money enriches the story. Indeed, a larger mean bond supply also increases the good's price. That is because a larger mean bond supply is associated with larger government consumption in period 1, and so, with fewer goods left over for investors, a higher good's price (recall that we are considering an exchange economy, so the supply of goods is fixed).[41,42] In turn, higher interest rate and good's price each increase price informativeness. These effects are more pronounced, the more transparent government policies are (i.e., the higher the precision of the bond and money supplies are) because the bond and money market signals are then more informative (Panel A of Figure 13). Put differently, more transparency increases the sensitivity of price informativeness to the interest rates. This makes policy implementation more efficient in that it allows the government to raise price informativeness without increasing the mean supply. These findings are supportive of critics who argue that, by purchasing government bonds through their QE programs, central banks have degraded informational efficiency. Finally, a higher mean bond supply increases the contribution of the interest rate to the total information available to investors relative other sources, such as the prior and the good's price (not shown).

The effect of the mean money supply largely mirrors that of the mean bond supply. A larger mean money supply increases both the good's price (since the supply of goods is fixed) and the (real) interest rate. The reason for the higher interest rate is that a larger supply

[40] There are many aspects to central bank communication and monetary policy transparency, and that literature is extensive (see, e.g., Blinder, Ehrmann, Fratzscher, de Haan, and Jansen 2008 for a survey). Using Geraats (2014, p. 5) classification of transparency, we focus here on "policy transparency," that is, on the "communication of the policy stance (including the policy decision, policy explanation and inclination with respect to future policy actions)."

[41] The positive relation between the interest rate and the period-1 good's price is easily understood when investors derive no utility real money balances (i.e., v is constant). In that case, the first-order condition with respect to an investor's money balance implies that $R_f = P_1^G / P_2^G$.

[42] Under more precise bond or money supplies, the good's price and interest rate curves shift upward due to a wealth effect. Indeed, more precise bond or money market signals magnify investors' expected trading profits, and so their desire to consume in period 1. Market clearing then requires a higher good's price and interest rate.

of money implies bigger government consumption in period 1, so that a larger interest rate is required in equilibrium to encourage investors to save rather than consume. In turn, the higher good's price and interest rate both amplify price informativeness (Panel B). These effects are larger the more precise the bond and money supplies, since the bond and money markets then convey more information about the stock supply.

A fiscal policy analysis yields straightforward results. Increasing the tax rate in period 1 crowds out private consumption in period 1 and increases the good's price and the interest rate. Both in turn improve the informativeness of the price system. These informational effects are more pronounced, the more transparent government policies are (higher τ_{θ_Y} and τ_{θ_M}).

7 Conclusion

In this paper, we show how the rate of interest affects the informativeness of financial markets. Specifically, we illustrate how rational investors use information contained in interest rates to learn about stock-market fundamentals. For that purpose, we develop a competitive noisy rational expectations equilibrium model in which the rate of interest is determined by supply and demand and, consequently, on top of serving as discount rate, reveals information.

We demonstrate that investors use the information revealed by interest rates to form posterior beliefs about the stock's supply (i.e., discount-rate news). As a result, investors can then more precisely infer the stock's payout from its price (i.e., cashflow news). Hence, in the presence of an endogenous rate of interest, price informativeness increases. Importantly, the strength of this effect is positively related to the interest rate. In particular, a higher interest rate reduces the importance of the (noisy) bond supply in the bond-market clearing condition, thereby dampening the noise of the bond-market signal. The enhanced signal-to-noise ratio of the bond-market signal makes it easier for investors to learn about the stock's supply.

We then analyse how variations in the characteristics of the bond market, in particular, the mean and the precision of its supply, affect informational efficiency in the stock market and, hence, asset prices. Naturally, the interest rate is increasing in the mean supply of the bond which in turn, leads to an increase in price informativeness (as discussed above). Moreover, it leads to a decline in the stock's return volatility, expected excess return, and the price of risk.

Finally, we document that the higher price informativeness resulting from higher interest rates, allows firms to make better informed real-investment decisions, thus improving real efficiency in the economy. We also study an extension of our main economic framework incorporating government spending, taxation and money. In this model, the rate of interest—together with the endogenous price of the consumption good—again allows investors to learn about the stock's supply. Importantly, this setting allows us to study how fiscal and monetary policies affect informational efficiency in the stock market through their impact on the bond market.

Overall, our theoretical analyses deliver a rich set of novel predictions. Most importantly, they point towards a negative relation between the informativeness of stock prices and real interest rates (or, equivalently, Treasury bond supply) and, consequently, to a decline in capital-allocation efficiency in period of low rates. We report robust empirical evidence lending support to this prediction. Our findings suggests a novel interpretation of the concomitant decline, observed since the 1980s, in aggregate productivity growth and real interest rates, namely that the downward trend in interest rates has impaired learning about the economic fundamentals and made the allocation of capital less efficient, which, in turn, slowed down productivity growth (Decker, Haltiwanger, Jarmin, and Miranda 2017). More research is needed to evaluate this interpretation.

Appendix

A Summary Statistics

Variable	Obs.	Mean	Median	Std. Dev.	Min	Max	ρ_1
Price Informativeness PI_5	50	0.049	0.050	0.011	0.023	0.073	0.475
Price Informativeness PI_3	50	0.040	0.040	0.010	0.021	0.062	0.431
Debt/GDP	50	0.369	0.358	0.123	0.209	0.754	0.854
FED MBS Hold./GDP	50	0.005	0.000	0.016	0.000	0.072	0.781
FED Treasury Hold./GDP	50	0.051	0.050	0.013	0.032	0.107	0.584
S&P500 Volatility	50	0.141	0.139	0.053	0.058	0.296	0.334
Cashflow Volatility	50	0.070	0.069	0.006	0.060	0.095	0.558
Real Interest Rate	50	0.026	0.027	0.027	-0.045	0.085	0.741

Table A1: Summary Statistics. The table reports summary statistics for our main variables. *Price Informativeness* $PI_h, h \in \{3,5\}$ refers to the coefficient, $b_{t,h}$, of the cross-sectional regression (1) multiplied by the cross-sectional standard deviation of (scaled) stock prices. *Debt/GDP* is the ratio of the market value of Treasury debt held by the public to U.S. GDP. *FED MBS Hold./GDP* and *FED Treasury Hold./GDP* are the ratio of the Federal Reserve banks' holdings of MBS and Treasury securities, divided by U.S. GDP. *S&P500 Volatility* and *Cashflow Volatility* are measures of volatility of, respectively, the S&P500 returns and of firms' earnings. *Real Interest Rate* is the nominal rate of long-term U.S. government bonds minus expected inflation. ρ_1 denotes the first-order autocorrelation.

	Base	1963-2009	5-year periods	FED: Treasury	Lagged variables	Volatility Controls	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Debt/GDP	0.027*	0.041**	0.027	0.021*	0.027*	0.034**	0.028*
	[1.72]	[2.70]	[1.01]	[1.81]	[2.00]	[2.19]	[1.69]
FED Hold./GDP	-0.183*		-0.141	-0.218*	-0.266***	-0.260	-0.200**
	[-1.83]		[-0.65]	[-1.74]	[-4.16]	[-2.25]**	[-2.23]
S&P500 Vola.						0.056*	
						[1.66]	
Cashflow Vola.							0.591***
							[3.23]
R^2	0.058	0.136	0.129	0.073	0.089	0.138	0.204
Observations	50	46	10	50	50	50	50

Table A2: Impact of Bond Supply and Demand on Stock-Price Informativeness PI_3. The table reports the results of regressions of price informativeness on Treasury-bond supply and demand. Throughout, the dependent variable is 3-year price informativeness, PI_3. *Debt/GDP* is the ratio of the market value of Treasury debt held by the public to U.S. GDP. *FED Hold./GDP* is the ratio of the Federal Reserve banks' holdings of MBS (or Treasury in Column (4)) divided by U.S. GDP. *S&P500 Vola.* and *Cashflow Vola.* are measures of volatility of, respectively, the S&P500 returns and firms' earnings. Regressions are estimated using OLS and standard errors are adjusted for serial correlation using the Newey-West procedure with five lags. We report t-statistics in brackets. *, **, and *** indicate significance at the 10%, 5%, and 1% level.

B Proofs and Derivations

Proof of Theorem 1, Lemma 1, and Lemma 2

We conjecture (and later verify) that the market-clearing conditions in the bond and the stock market are linear in the state variables:[43]

$$0 = b_X\,\theta_X + b_Y\,\theta_Y, \tag{A1}$$

$$R_f\,P = a_0 + a_\Pi\,\Pi + a_X\,\theta_X. \tag{A2}$$

They both serve as public signals for investors. Specifically, the bond-market-clearing condition (A1) provides a signal on the stock supply, θ_X, thus allowing investors to form posterior beliefs, namely posterior precision $\tau_{\theta_X|R_f}$ and posterior mean $\mu_{\theta_X|R_f}$, regarding θ_X:

$$\tau_{\theta_X|R_f} = \tau_{\theta_X} + \frac{b_X^2}{b_Y^2}\,\tau_{\theta_Y}, \tag{A3}$$

$$\mu_{\theta_X|R_f} = \frac{\tau_{\theta_X}}{\tau_{\theta_X|R_f}}\,\mu_{\theta_X} + \frac{1}{\tau_{\theta_X|R_f}}\,\frac{b_X^2}{b_Y^2}\,\tau_{\theta_Y}\left(-\frac{b_Y}{b_X}\right)\mu_{\theta_Y}. \tag{A4}$$

Combining these posterior beliefs regarding the stock supply with an investor's prior information about Π, her private signal, $S_i = \Pi + \varepsilon_i$, and the conjectured stock-price signal, $R_f P$, in (A2), yields an investor's posterior beliefs regarding the stock payoff, Π:

$$\tau \equiv \mathbb{V}\mathrm{ar}(\Pi\,|\,R_f, S_i, P) = \tau_\Pi + \tau_\varepsilon + \frac{a_\Pi^2}{a_X^2}\,\tau_{\theta_X|R_f}; \quad \text{and} \tag{A5}$$

$$\begin{aligned}\mathbb{E}\left[\Pi\,|\,R_f, S_i, P\right] &= \frac{\tau_\Pi}{\tau}\,\mu_\Pi + \frac{\tau_\varepsilon}{\tau}\,S_i + \frac{1}{\tau}\,\frac{a_\Pi^2}{a_X^2}\,\tau_{\theta_X|R_f}\,\frac{R_f P - a_0 - a_X\,\mu_{\theta_X|R_f}}{a_\Pi} \\ &= \frac{1}{\tau}\left(\tau_\Pi\mu_\Pi - \frac{a_\Pi}{a_X^2}\,\tau_{\theta_X|R_f}\left(a_0 + a_X\,\mu_{\theta_X|R_f}\right)\right) + \frac{\tau_\varepsilon}{\tau}\,S_i + \frac{\tau_{\theta_X|R_f}}{\tau}\,\frac{a_\Pi}{a_X^2}\,R_f P.\end{aligned} \tag{A6}$$

[43] Or, equivalently, if written explicitly in the form of the market-clearing conditions:

$$-\frac{b_X}{b_Y}\,\theta_X = \theta_Y, \quad \text{and} \quad \frac{1}{a_X}\left(R_f\,P - a_0 - a_\Pi\,\Pi\right) = \theta_X.$$

Solving the period-1 budget equation in (7) for the bond holdings, Y_i, yields:

$$Y_i = R_f \, (W_{i,1} - X_i \, P) \,, \tag{A7}$$

which can be used to re-write the period-2 budget equation in (7) as:

$$C_{i,2} = R_f \, W_{i,1} + X_i \, (\Pi - P) \,. \tag{A8}$$

Plugging the period-2 consumption (A8) into the investor's utility function (6) and maximizing the utility with respect to X_i, results in the traditional CARA optimal stock demand:

$$X_i = \frac{\mathbb{E}[\Pi \,|\, R_f, S_i, P] - P \, R_f}{\gamma \, \mathbb{V}\mathrm{ar}(\Pi \,|\, R_f, S_i, P)}. \tag{A9}$$

Aggregating investors' bond demand (A7), equating it to bond supply θ_Y, and imposing market clearing in the stock market, implies:

$$\begin{aligned}\int_0^1 Y_i \, di &= \int_0^1 R_f \, (X_{i,0} \, (\Pi_1 + P) - X_i \, P) \, di \\ &= R_f \, (\theta_X \, (\Pi_1 + P) - \theta_X P) = R_f \, \Pi_1 \, \theta_X \triangleq \theta_Y,\end{aligned}$$

where we used that $W_{i,1} = X_{i,0} \, (\Pi_1 + P)$ and $\int_0^1 X_{i,0} = \theta_X$. This verifies conjecture (A1), and (by matching coefficients) directly yields:

$$b_X = R_f \, \Pi_1 \qquad \text{and} \qquad b_Y = -1. \tag{A10}$$

As a result, investors' posterior mean and precision regarding the stock supply, (A3) and (A4), are given by:

$$\tau_{\theta_X|R_f} = \tau_{\theta_X} + \Pi_1^2 \, R_f^2 \, \tau_{\theta_Y}, \quad \text{and} \quad \mu_{\theta_X|R_f} = \frac{\tau_{\theta_X}}{\tau_{\theta_X|R_f}} \, \mu_{\theta_X} + \frac{R_f^2 \, \Pi_1^2 \, \tau_{\theta_Y}}{\tau_{\theta_X|R_f}} \, \frac{\mu_{\theta_Y}}{R_f \, \Pi_1}. \tag{A11}$$

Plugging the investors' posterior beliefs (A5) and (A6) regarding payoff Π (replacing b_X and b_Y with (A10)) into the stock demand (A9), aggregating across investors, and equating to supply θ_X, yields:

$$\int_0^1 X_i di = \int_0^1 \frac{\tau}{\gamma} \left\{ \frac{1}{\tau} \left(\tau_\Pi \mu_\Pi - \frac{a_\Pi \, \tau_{\theta_X|R_f}}{a_X^2} \left(a_0 + a_X \mu_{\theta_X|R_f} \right) \right) + \frac{\tau_\varepsilon}{\tau} S_i + \frac{\tau_{\theta_X|R_f}}{\tau} \frac{a_\Pi}{a_X^2} R_f P - R_f P \right\} di$$

$$= \frac{1}{\gamma} \left(\tau_\Pi \mu_\Pi - \frac{a_\Pi \tau_{\theta_X|R_f}}{a_X^2} \left(a_0 + a_X \mu_{\theta_X|R_f} \right) \right) + \frac{\tau_\varepsilon}{\tau} \Pi + \frac{1}{\gamma} \left(\frac{a_\Pi \tau_{\theta_X|R_f}}{a_X^2} - \tau \right) R_f P \triangleq \theta_X. \tag{A12}$$

which verifies conjecture (A2). Finally, matching the coefficients of (A12) to the ones of the conjecture (A2), and solving the resulting equation system for a_0, a_Π, and a_X, yields:

$$a_0 = \frac{\tau_\Pi}{\tau} \mu_\Pi + \frac{\tau_\epsilon \, \tau_{\theta_X|R_f}}{\gamma \, \tau} \mu_{\theta_X|R_f}, \tag{A13}$$

$$a_\Pi = \frac{\tau_\epsilon \left(\gamma^2 + \tau_\epsilon \, \tau_{\theta_X|R_f} \right)}{\tau \, \gamma^2}, \quad \text{and} \quad a_X = -\frac{\tau_\epsilon \left(\gamma^2 + \tau_\epsilon \, \tau_{\theta_X|R_f} \right)}{\tau \, \gamma^2} \frac{\gamma}{\tau_\epsilon}. \tag{A14}$$

Hence, investors' posterior precision regarding Π, (A5), is given by:

$$\tau = \tau_\Pi + \tau_\varepsilon + \frac{\tau_\varepsilon^2}{\gamma^2} \tau_{\theta_X|R_f}. \tag{A15}$$

Theorem 1 follows readily from i) plugging coefficients (A10) into the conjecture for the bond-market-clearing condition (A1), ii) plugging coefficients (A13) and (A14) into the conjecture for the stock-market-clearing condition (A2), iii) the optimal bond and stock demand (A7) and (A9), and iv) posterior beliefs (A11) and (A15).

Lemmas 1 and 2 follow immediately from (A11) and (A15), respectively.

Derivation of Equation 15

Solving the period-1 budget equation in (4) for the bond holdings, Y_i, yields:

$$Y_i = R_f \, (W_{i,1} - X_i \, P - C_{i,1}) \, .$$

Aggregating this bond demand across investors, equating it to bond supply θ_Y, and imposing market clearing in the stock market, implies:

$$\int_0^1 Y_i\, di = \int_0^1 R_f\ (X_{i,0}\,(\Pi_1 + P) - X_i\, P - C_{i,1})\ di$$
$$= R_f\ \left(\theta_X\,(\Pi_1 + P) - \theta_X P - \int_0^1 C_{i,1}\, di\right) = R_f\, \Pi_1\, \theta_X - R_f \int_0^1 C_{i,1}\, di \triangleq \theta_Y,$$

which is equivalent to **Equation 15**.

Derivation of Equations 19 and 21

Taking the first-order condition of the manager's conditional expectation $\mathbb{E}\left[v(a, I) \mid R_f, P\right]$ with respect to real investment, I, yields:

$$-1 + \mathbb{E}\left[(1 + a) - \frac{c}{K_1}\, I \,\middle|\, P, R_f\right] = 0,$$

which is equivalent to **Equation 19**.

Plugging the optimal investment, I, in (19) into the fundamental firm value (18) (scaled by assets in place, K_1) and simplifying, yields:

$$\frac{v\big(a, (K_1/c)\mathbb{E}\left[a|P, R_f\right]\big)}{K_1} = \left(1 - \frac{\mathbb{E}\left[a|P, R_f\right]}{c}\right) + (1 + a)\left(1 - \delta + \frac{\mathbb{E}\left[a|P, R_f\right]}{c}\right) - \frac{1}{2c}\,\mathbb{E}\left[a|P, R_f\right]^2$$
$$= 2 - \delta + a + \frac{a}{c}\,\mathbb{E}\left[a \mid P, R_f\right] - \frac{1}{2c}\,\mathbb{E}\left[a \mid P, R_f\right]^2. \tag{A16}$$

Next, computing the expectation of (A16) under the manager's information set, gives:

$$\mathbb{E}\left[\frac{v\big(a, (K_1/c)\mathbb{E}\left[a|P, R_f\right]\big)}{K_1} \,\middle|\, R_f, P\right] = 2 - \delta + \mathbb{E}\left[a|P, R_f\right] + \frac{1}{2c}\,\mathbb{E}\left[a|P, R_f\right]^2. \tag{A17}$$

Real efficiency, $\mathcal{E}$, in (20), is then simply the unconditional expectation of (A17) and, hence, given by:

$$\mathcal{E} = 2 - \delta + \mu_a + \frac{1}{2c}\,\mathbb{E}\left[\mathbb{E}\left[a|P, R_f\right]^2\right] = 2 - \delta + \mu_a + \frac{1}{2c}\ \left(\mathbb{V}ar\big(\mathbb{E}\left[a|P, R_f\right]\big) + \mu_a^2\right)$$
$$= 2 - \delta + \mu_a\ \left(1 + \frac{\mu_a}{2c}\right) + \frac{1}{2c}\,\mathbb{V}ar\big(\mathbb{E}\left[a|P, R_f\right]\big),$$

which, using the law of total variance, can be written as **Equation 21**.

Derivation of Equation 24

Solving the period-1 budget equation in (23) for the money holdings, M_i, yields:

$$M_i = P_1^G \left(W_{i,1} - T_{i,1} - C_{i,1} - X_i\,P - Y_i\,R_f^{-1}\right).$$

Aggregating the money demand across investors, equating it to money supply θ_M, and imposing market-clearing in the bond as well as the stock market, implies:

$$\begin{aligned}\int_0^1 M_i\,di &= \int_0^1 P_1^G \left(W_{i,1} - T_{i,1} - C_{i,1} - X_i\,P - Y_i\,R_f^{-1}\right)\,di \\ &= P_1^G \left(\theta_X\,(\Pi_1 + P) - \int_0^1 T_{i,1}\,di - \int_0^1 C_{i,1}\,di - \theta_X\,P - R_f \theta_Y\right) \triangleq \theta_M,\end{aligned}$$

which can be written as

$$0 = \theta_X - \frac{\theta_Y}{R_f\,\Pi_1} - \frac{\theta_M}{P_1^G\,\Pi_1} - \frac{1}{\Pi_1}\int_0^1 (C_{i,1} - T_{i,1})\,di.$$

Finally, setting taxes ($T_{i,1}$), consumption ($C_{i,1}$), and bond supply (θ_Y) to zero, recovers **Equation 24**.

C Numerical Solution Approach

The key difficulty in identifying the equilibrium in our economic frameworks is that, in contrast to traditional CARA-normal models, the market-clearing conditions in the stock and the bond market are a nonlinear functions of the state variables, with unknown functional forms. As a result, one cannot explicitly compute the investors' posterior beliefs and, hence, cannot find a closed-form solution for the equilibrium. Accordingly, the model has to be solved numerically.

For that purpose, we extend the numerical solution approach presented in Breugem and Buss (2019) to allow for learning from the interest rate and two-period consumption. The approach allows for arbitrary price and demand functions, that is, one does not need to parameterize (conjecture) these functions in any form. Also, it identifies the equilibrium *exactly*—up to a discretization of the state space (which can be made arbitrarily narrow). The algorithm comprises the following four key steps.

First, we discretize the state space into a grid of N_Π, N_{θ_X}, and N_{θ_Y} realizations of the random variables Π, θ_X, and θ_Y, respectively.[44]

Second, we form, for any given grid point $\Omega = \{\Pi_n, \theta_{X_m}, \theta_{Y_o}\}$, where $n \in \{1, \ldots, N_\Pi\}$, $m \in \{1, \ldots, N_{\theta_X}\}$, $o \in \{1, \ldots, N_{\theta_Y}\}$, the system of equations that characterizes the equilibrium. The system is composed of investors' first-order conditions with respect to bond and stock holdings, plus the two market-clearing conditions (5).[45] Specifically, to accommodate investors' dispersed signal realizations, we form N_S groups of investors ("signal-realization groups") for each grid point Ω, with each group receiving a different signal S_s, $s \in \{1, \ldots, N_S\}$. Thus, we arrive at an equation system with $N_S \times 2 + 2$ equations, with unknowns: $\{R_f(\Omega), P(\Omega)\}$ and $\{X_s(\Omega), Y_s(\Omega)\}$, $\forall s \in \{1, \ldots, N_S\}$ (i.e., $2 + N_S \times 2$ unknowns in total).

Third, we complement the equation system with a set of equations that characterize investors' rational expectations.[46] Specifically, for each signal-realization group s and each "conjectured" payoff $\hat{\Pi}_v$, $v \in \{1, \ldots, V\}$, we add equations that—under the beliefs of group s and conditional on prices—describe the aggregate demand for the two assets.[47,48] This requires solving for the optimal bond and stock demand of all signal-realization groups and all conjectured payoffs—under group s's beliefs and conditional on prices—and aggregating the resultant demands. This adds $N_S^2 \times V \times 2$ equations for each grid point Ω, though many of them are redundant and, thus, can be removed. Based on the aggregate demands, $\{\hat{\theta}_{X_v}, \hat{\theta}_{Y_v}\}$, for all conjectured payoffs $\{\hat{\Pi}_v\}$, $v \in \{1, \ldots, V\}$, each group s can then compute

[44] We truncate the realizations of the bond supply, θ_Y, such that $\theta_Y \geq 0$. This is needed because, under CARA-preferences, the equilibrium might not exist for $\theta_Y < 0$, due to the violation of the Inada conditions.

[45] For ease of computation, we use the budget equations (4) to replace an investor's consumption choices with $C_{i,1} = W_{i,1} - X_i P - Y_i R_f^{-1}$ and $C_{i,2} = X_i \Pi + Y_i$ in her utility function.

[46] If investors' posterior probabilities were "exogenous" (e.g., a function of their private signals or their prior beliefs only), one could directly solve the equation system described in step 2. However, under rational expectations, investors' beliefs depend on the two assets' prices; giving rise to a fixed-point problem.

[47] To distinguish between the actual values of the payoff and the asset supplies at a given grid point, $\{\Pi_n, \theta_{X_m}, \theta_{Y_o}\}$, and conjectured payoffs and asset supplies, $\{\hat{\Pi}, \hat{\theta}_X, \hat{\theta}_Y\}$, we denote the later with a "$\hat{}$".

[48] To allow for conjectured payoffs to cover a wide range around the actual payoff Π_n, we create a separate grid specific to the conjectured payoffs, with entries $\{\hat{\Pi}_1, \ldots, \hat{\Pi}_V\}$.

her posterior probabilities (employed in the first-order conditions) using the the distribution of the bond's and the stock's supply.[49]

Fourth, for each grid point Ω, we solve this large-scale fixed point problem using Mathematica. In particular, we rely on `FindRoot` which uses a damped version of the Newton-Raphson method together with finite differences to compute the Hessian.

We find that the solution of the system is very accurate for $N_\Pi = N_{\theta_X} = N_{\theta_Y} = 9$, $N_S = 45$, and $V = 45$. Further increasing the number of discretization points hardly changes the solution. For that choice, solving the system of equations for one grid point takes about 0.8 seconds on an Intel Core i7 workstation. Hence, solving it for all 729 grid points requires less than 10 minutes.[50]

D Two-Stock Extension

The model with two stocks is a straightforward extension of the (one-stock) version presented in Section 2. In particular, investors consume in two periods and the rate of interest is determined endogenously, with investors learning from it.

The two (symmetric) stocks, $k \in \{1, 2\}$, are modelled as claims to random payoffs, $\Pi^{(k)} \sim \mathcal{N}(\mu_\Pi, \tau_\Pi)$, with prices $P^{(k)}$. Each stock also pays a deterministic payoff, $\Pi_1^{(k)} > 0$, in period 1. Both stocks have a residual supply, $\theta_X^{(k)} \sim \mathcal{N}(\mu_{\theta_X}, \tau_{\theta_X})$. For illustration purposes, payoffs and supplies are assumed to be independent across stocks.

Each investor, i, receives private signals (with exogenous precision) regarding the two stocks' payoffs: $S_i^{(k)} = \Pi^{(k)} + \varepsilon_i^{(k)}$, with $\varepsilon_i^{(k)} \sim \mathcal{N}(0, \tau_\varepsilon)$. She is endowed with $X_{i,0}^{(k)}$ shares of each stock, which aggregate to the supply $\theta_X^{(k)}$ and are uninformative. Her objective is to maximize expected (CARA-) utility (3)—conditional on her information set $\mathcal{F}_i =$

[49] Formally, the posterior probability of group s for a payoff $\hat{\Pi}_{v'}$, conditional on prices and her private signal S_s, is given by:

$$\mathbb{P}\left(\hat{\Pi}_{v'} \,|\, R_f, P, S_s\right) = \frac{f_{\theta_X}\left(\hat{\theta}_{X_{v'}}\right) f_{\theta_Y}\left(\hat{\theta}_{Y_{v'}}\right) f_\Pi\left(\hat{\Pi}_{v'} \,|\, S_s\right)}{\sum_{v=1}^{V} f_{\theta_X}\left(\hat{\theta}_{X_v}\right) f_{\theta_Y}\left(\hat{\theta}_{Y_v}\right) f_\Pi\left(\hat{\Pi}_v \,|\, S_s\right)},$$

where f_Π, f_{θ_X}, and f_{θ_Y} denote the *exact* density functions of the payoff Π, the stock supply θ_X, and the bond supply θ_Y, respectively.

[50] To verify the solution approach, we have, among others, used the numerical approach i) to replicate our closed-form solution for the economy without initial consumption (see Section 3), ii) to replicate the Hellwig (1980) solution in an economy without learning from the interest rate and without initial consumption, and iii) to confirm that the solution converges to the solution without private information as τ_ε converges to zero.

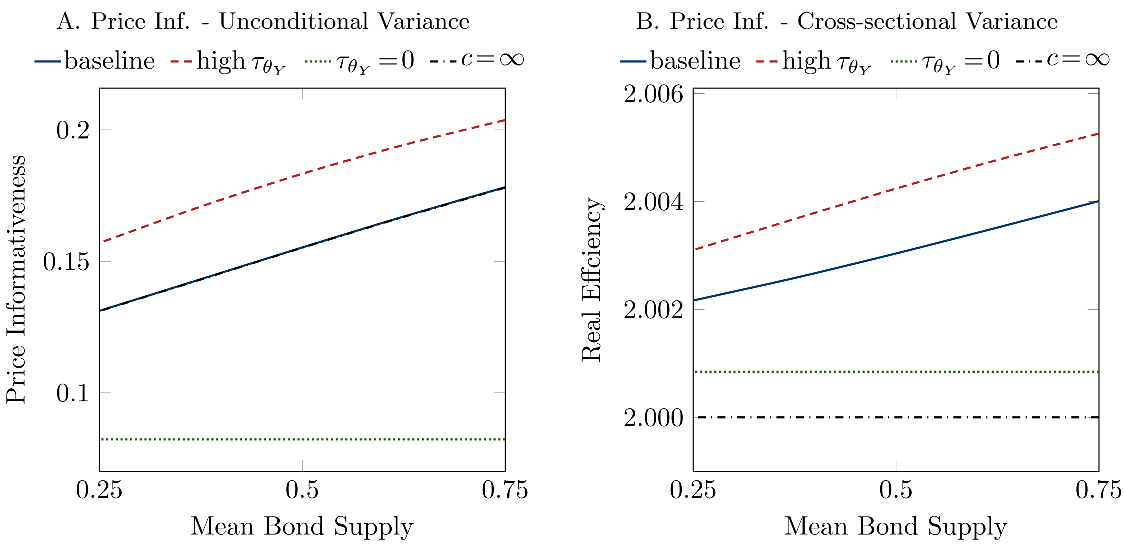

Figure A1: Price Informativeness (*in the presence of initial consumption and with two stocks*). Figure needs to be inserted. The graphs plot price informativeness as a function of the mean bond supply, μ_{θ_Y}—for three different values for the prior precision of the bond supply, τ_{θ_Y}. In Panel A, price informativeness is calculated (for stock 1) as in (16), i.e., as the square root of the *unconditional* variance of the predictable component of $\Pi^{(1)}$ conditional on prices. In Panel B, price informativeness is calculated as expecation of the square root of the *cross-sectional* variance of the predictable components of the two stocks' payoffs $\Pi^{(k)}$ conditional on prices. The graphs are based on the following baseline parameter values: $\beta = 1$, $\gamma = 1$, $\Pi_1^{(k)} = 1/2$, $\mu_\Pi = 1$, $\tau_\Pi = 4^2$, $\tau_\epsilon = 0.5^2$, $\mu_{\theta_X} = 1$, $\tau_{\theta_X} = 8^2$, and $\tau_{\theta_Y} = 8^2$. High τ_{θ_Y} describes an economy with a higher precision of the bond supply and $\tau_{\theta_Y} = 0$ describes an economy in which investors do not learn from the rate of interest.

$\{S_i^{(1)}, S_i^{(2)}, R_f, P^{(1)}, P^{(2)}\}$—subject to the following budget equations:

$$C_{i,1} + X_i^{(1)} P^{(1)} + X_i^{(2)} P^{(2)} + Y_i R_f^{-1} = W_{i,1}, \quad \text{and} \quad C_{i,2} = X_i^{(1)} \Pi^{(1)} + X_i^{(2)} \Pi^{(2)} + Y_i, \tag{A18}$$

where $X_i^{(k)}$ denotes the number of shares of stock k held by investor i, and endowed wealth, $W_{i,1}$ is given by: $W_{i,1} = X_{i,0}^{(1)}(P^{(1)} + \Pi_1^{(1)}) + X_{i,0}^{(2)}(P^{(2)} + \Pi_1^{(2)})$.

Equilibrium is defined by consumption and investment choices, $\{C_{i,1}, C_{i,2}, X_i^{(1)}, X_i^{(2)}, Y_i\}$ and asset prices $\{P^{(1)}, P^{(2)}, R_f\}$ such that: i) $\{C_{i,1}, C_{i,2}, X_i^{(1)}, X_i^{(2)}, Y_i\}$ maximize investor i's expected utility (3) subject to the budget constraints (A18); ii) investors' expectations are rational; and iii) aggregate demand equals aggregate supply—in the bond and the two stock markets. Due to the presence of initial consumption (which renders the market-clearing condition in the bond market non-linear), the equilibrium is again identified numerically. The details of the solution approach can be found in Appendix D.

An analysis of the equilibrium indicates that our four main findings are robust to the addition of the second stock. First, investors use information revealed by the interest rate to form posterior beliefs regarding the stocks' supplies. In fact, the bond-market clearing condition now also connects the two stocks' supplies, creating an endogenous correlation between their excess returns (discussed in detail in Section 4.4). Second, as illustrated in (17), the precision of the bond-market signal and hence, information about each stock continue to be increasing in the rate of interest R_f. Third, and a consequence of our second finding, the informativeness of each stock's price (16), calculated as the (square root of the) unconditional variance of the predictable component of its payoff, $\Pi^{(k)}$, conditional on prices, is increasing in the mean and the precision of the bond supply (Panel A of Figure A1).[51] Notably, the two-stock extension also allows to compute price informativeness as the (square root of the) *cross-sectional* variance of the predictable component of the stocks' payouts, $\Pi^{(k)}$, conditional on prices—matching the proxy (2) used in our empirical investigation. As Panel B shows, it follows exactly the same patterns as our standard definition of price informativeness (plotted in Panel A); that is, it is increasing in the mean and the precision of the bond supply.[52] Finally, all implications regarding the impact of the mean and the precision of the bond supply on investors' consumption choices and asset prices (mean and variance of excess returns, price of risk) carry over from the one-stock economy.

[51] The figure plots price informativeness for stock $k = 1$ which, given symmetry, coincides with that of stock 2.

[52] Because we focus on two symmetric stocks, variations in the cross-sectional variance are rather limited. Specifically, symmetry implies that the conditional expectations of the two stocks payoffs (and, in fact, their prices) do not deviate too much from each other. Moreover, we only consider two stocks and not hundreds (as in the empirical analysis).

References

Admati, A., 1985, "A Noisy Rational Expectations Equilibrium for Multi-asset Securities Markets," *Econometrica*, 53(3), 629–657.

Albagli, E., C. Hellwig, and A. Tsyvinski, 2015, "A Theory of Asset Prices Based on Heterogeneous Information," *Working Paper*.

Andolfatto, D., and A. Spewak, 2018, "On the Supply of, and Demand for, U.S. Treasury Debt," *Economic Synopses*, 5.

Ang, A., M. Piazzesi, and M. Wei, 2006, "What Does the Yield Curve Tell Us about GDP Growth?," *Journal of Econometrics*, 131(1), 359–403.

Bai, J., T. Philippon, and A. Savov, 2016, "Have Financial Markets Become More Informative?," *Journal of Financial Economics*, 122(3), 625–654.

Bakke, T.-E., and T. M. Whited, 2010, "Which Firms Follow the Market? An Analysis of Corporate Investment Decisions," *Review of Financial Studies*, 23(5), 1941–1980.

Banerjee, S., and B. Green, 2015, "Signal or noise? Uncertainty and learning about whether other traders are informed," *Journal of Financial Economics*, 117(2), 398–423.

Barlevy, G., and P. Veronesi, 2000, "Information Acquisition in Financial Markets," *Review of Economic Studies*, 67(1), 79–90.

——— , 2003, "Rational Panics and Stock Market Crashes," *Journal of Economic Theory*, 110(2), 234–263.

Baxter, M., and R. G. King, 1993, "Fiscal Policy in General Equilibrium," *American Economic Review*, 83(3), 315–334.

Bernanke, B., and M. Gertler, 1989, "Agency Costs, Net Worth, and Business Fluctuations," *American Economic Review*, 79(1), 14–31.

Biais, B., P. Bossaerts, and C. Spatt, 2010, "Equilibrium Asset Pricing and Portfolio Choice Under Asymmetric Information," *Review of Financial Studies*, 23(4), 1503–1543.

Biais, B., J. Hombert, and P.-O. Weill, 2014, "Equilibrium Pricing and Trading Volume under Preference Uncertainty," *Review of Economic Studies*, 81(4), 1401–1437.

Blinder, A. S., M. Ehrmann, M. Fratzscher, J. de Haan, and D.-J. Jansen, 2008, "Central Bank Communication and Monetary Policy: A Survey of Theory and Evidence," *Journal of Economic Literature*, 46(4), 910–945.

Bond, P., A. Edmans, and I. Goldstein, 2012, "The Real Effects of Financial Markets," *Annual Review of Financial Economics*, 4(1), 339–360.

Brennan, M. J., and H. H. Cao, 1997, "International Portfolio Investment Flows," *Journal of Finance*, 52(5), 1851–1880.

Breon-Drish, B., 2015, "On Existence and Uniqueness of Equilibrium in a Class of Noisy Rational Expectations Models," *Review of Economic Studies*, 82(3), 868–921.

Breugem, M., and A. Buss, 2019, "Institutional Investors and Information Acquisition: Implications for Asset Prices and Informational Efficiency," *Review of Financial Studies*, 32(6), 2260–2301.

Brunnermeier, M. K., and L. H. Pedersen, 2008, "Market Liquidity and Funding Liquidity," *Review of Financial Studies*, 22(6), 2201–2238.

Brunnermeier, M. K., and Y. Sannikov, 2014, "A Macroeconomic Model with a Financial Sector," *American Economic Review*, 104(2), 379–421.

Chen, Q., I. Goldstein, and W. Jiang, 2007, "Price Informativeness and Investment Sensitivity to Stock Price," *Review of Financial Studies*, 20(3), 619–650.

Croce, M. M., H. Kung, T. T. Nguyen, and L. Schmid, 2012, "Fiscal Policies and Asset Prices," *Review of Financial Studies*, 25(9), 2635–2672.

Croce, M. M., T. Nguyen, and L. Schmid, 2012, "The Market Price of Fiscal Uncertainty," *Journal of Monetary Economics*, 59(5), 401–416.

Danthine, J.-P., and J. Donaldson, 1986, "Inflation and Asset Prices in an Exchange Economy," *Econometrica*, 54(3), 585–605.

Decker, R. A., J. Haltiwanger, R. S. Jarmin, and J. Miranda, 2017, "Declining Dynamism, Allocative Efficiency, and the Productivity Slowdown," *American Economic Review*, 107(5), 322–326.

Dessaint, O., T. Foucault, L. Frésard, and A. Matray, 2018, "Noisy Stock Prices and Corporate Investment," *Review of Financial Studies*, 32(7), 2625–2672.

Dotsey, M., 1990, "The Economic Effects of Production Taxes in a Stochastic Growth Model," *American Economic Review*, 80(5), 1168–1182.

Durnev, A., R. Morck, and B. Yeung, 2004, "Value-Enhancing Capital Budgeting and Firm-specific Stock Return Variation," *Journal of Finance*, 59(1), 65–105.

Edmans, A., I. Goldstein, and W. Jiang, 2015, "Feedback Effects, Asymmetric Trading, and the Limits to Arbitrage," *American Economic Review*, 105(12), 3766–3797.

Estrella, A., and F. S. Mishkin, 1998, "Predicting U.S. Recessions: Financial Variables as Leading Indicators," *Review of Economics and Statistics*, 80(1), 45–61.

Farboodi, M., and L. Veldkamp, 2019, "Long Run Growth of Financial Technology," *American Economic Review*, forthcoming.

Foucault, T., and L. Frésard, 2014, "Learning from Peers' Stock Prices and Corporate Investment," *Journal of Financial Economics*, 111(3), 554–577.

Ganguli, J. V., and L. Yang, 2009, "Complementarities, Multiplicity, and Supply Information," *Journal of the European Economic Association*, 7(1), 90–115.

Geraats, P., 2014, "Monetary Policy Transparency," CESifo Working Paper Series 4611, CESifo Group Munich.

Gomes, F., A. Michaelides, and V. Polkovnichenko, 2013, "Fiscal Policy and Asset Prices with Incomplete Markets," *Review of Financial Studies*, 26(2), 531–566.

Gopinath, G., Ş. Kalemli-Özcan, L. Karabarbounis, and C. Villegas-Sanchez, 2017, "Capital Allocation and Productivity in South Europe," *Quarterly Journal of Economics*, 132(4), 1915–1967.

Gorton, G., S. Lewellen, and A. Metrick, 2012, "The Safe-Asset Share," *American Economic Review*, 102(3), 101–106.

Grossman, S. J., and J. E. Stiglitz, 1980, "On the Impossibility of Informationally Efficient Markets," *American Economic Review*, 70(3), 393–408.

Harvey, C. R., 1988, "The Real Term Structure and Consumption Growth," *Journal of Financial Economics*, 22(2), 305–333.

Hayashi, F., 1982, "Tobin's Marginal q and Average q: A Neoclassical Interpretation," *Econometrica*, 50(1), 213–224.

He, Z., and A. Krishnamurthy, 2013, "Intermediary Asset Pricing," *American Economic Review*, 103(2), 732–770.

Hellwig, M. F., 1980, "On the Aggregation of Information in Competitive Markets," *Journal of Economic Theory*, 22(3), 477–498.

Kacperczyk, M., S. van Nieuwerburgh, and L. Veldkamp, 2016, "A Rational Theory of Mutual Funds' Attention Allocation," *Econometrica*, 84(2), 571–626.

Kiyotaki, N., and J. Moore, 1997, "Credit Cycles," *Journal of Political Economy*, 105(2), 211–248.

Kodres, L. E., and M. Pritsker, 2002, "A Rational Expectations Model of Financial Contagion," *Journal of Finance*, 57(2), 769–799.

Koeva, P., 2000, "The Facts About Time-to-Build," IMF Working paper.

Krishnamurthy, A., and A. Vissing-Jorgensen, 2012, "The Aggregate Demand for Treasury Debt," *Journal of Political Economy*, 120(2), 233–267.

LeRoy, S. F., 1984a, "Nominal Prices and Interest Rates in General Equilibrium: Endowment Shocks," *Journal of Business*, 57(2), 197–213.

——— , 1984b, "Nominal Prices and Interest Rates in General Equilibrium: Money Shocks," *Journal of Business*, 57(2), 177–195.

Lowenstein, M., and G. A. Willard, 2006, "The Limits of Investor Behavior," *Journal of Finance*, 61(1), 231–258.

Lucas, R. E., 1982, "Interest Rates and Currency Prices in a Two-Country World," *Journal of Monetary Economics*, 10(3), 335–359.

Ludvigson, S., 1996, "The Macroeconomic Effects of Government Debt in a Stochastic Growth Model," *Journal of Monetary Economics*, 38(1), 25–45.

Luo, Y., 2005, "Do Insiders Learn from Outsiders? Evidence from Mergers and Acquisitions," *Journal of Finance*, 60(4), 1951–1982.

Manzano, C., and X. Vives, 2011, "Public and Private Learning from Prices, Strategic Substitutability and Complementarity, and Equilibrium Multiplicity," *Journal of Mathematical Economics*, 47(3), 346 – 369.

Marshall, D. A., 1992, "Inflation and Asset Returns in a Monetary Economy," *Journal of Finance*, 47(4), 1315–1342.

Mishkin, F. S., 1990, "The Information in the Longer Maturity Term Structure About Future Inflation," *Quarterly Journal of Economics*, 105(3), 815–828.

Newey, W. K., and K. D. West, 1994, "Automatic Lag Selection in Covariance Matrix Estimation," *Review of Economic Studies*, 61(4), 631–653.

Pástor, Ľ., and P. Veronesi, 2012, "Uncertainty about Government Policy and Stock Prices," *Journal of Finance*, 67(4), 1219–1264.

Peress, J., 2004, "Wealth, Information Acquisition, and Portfolio Choice," *Review of Financial Studies*, 17(3), 879–914.

Rampini, A. A., and S. Viswanathan, 2010, "Collateral, Risk Management, and the Distribution of Debt Capacity," *Journal of Finance*, 65(6), 2293–2322.

Sellin, P., 2001, "Monetary Policy and the Stock Market: Theory and Empirical Evidence," *Journal of Economic Surveys*, 15(4), 491–541.

Svensson, L., 1985, "Money and Asset Prices in a Cash-in-Advance Economy," *Journal of Political Economy*, 93(5), 919–944.

Tobin, J., 1969, "A General Equilibrium Approach To Monetary Theory," *Journal of Money, Credit and Banking*, 1(1), 15–29.

van Nieuwerburgh, S., and L. Veldkamp, 2009, "Information Immobility and the Home Bias Puzzle," *Journal of Finance*, 64(3), 1187–1215.

——— , 2010, "Information Acquisition and Under-Diversification," *Review of Economic Studies*, 77(2), 779–805.

Verrecchia, R. E., 1982, "Information Acquisition in a Noisy Rational Expectations Economy," *Econometrica*, 50(6), 1415–1430.

Watanabe, M., 2008, "Price Volatility and Investor Behavior in an Overlapping Generations Model with Information Asymmetry," *Journal of Finance*, 63(1), 229–272.

Yang, L., and H. Zhu, 2019, "Back-Running: Seeking and Hiding Fundamental Information in Order Flows," *Review of Financial Studies*, 33(4), 1484–1533.