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Financial Innovation and Asset Prices

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We study how the dynamics of asset prices are affected by financial innovation, which makes a new asset class available to investors who previously did not have access to it. The traditional view is that financial innovation enhances risk sharing and consumption smoothing, leading to a decrease in the return volatility and risk premium of the new asset. We show that this view depends crucially on the assumption of homogeneous beliefs: When some investors are less well informed about the new asset class but rationally learn about it, these "intuitive" results are reversed; financial innovation *increases* portfolio volatility of investors along with the return volatility and risk premium for the new asset, which decline to the pre-innovation level only slowly over several decades. Moreover, if the new asset is also less liquid than traditional assets, then shocks to the cash flows of the new asset spill over to the traditional asset, increasing their return correlation and giving rise to a liquidity premium for the new asset.

Keywords: Financial Innovation; Heterogeneous Beliefs; Parameter Uncertainty; Rational Learning; Spillover Effects; Recursive Utility
JEL Classification: G11, G12

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1 Introduction

Financial markets have been transformed by the rapid pace of financial innovation, which makes available new asset classes to investors who previously did not have access to them. At the same time, demand for new asset classes[1] is high because in the current economic environment returns on traditional asset classes have fallen and correlations between them have increased, leading to poor portfolio performance. Our objective in this paper is to understand the impact of financial innovation on the dynamics of asset prices.

The traditional view about financial innovation (see, for example, Kihlstrom, Romer, and Williams (1981), Allen and Gale (1988), Weil (1992), and Elul (1997)) is that it improves risk sharing across investors while also improving diversification of each investor's portfolio. Thus, financial innovation should smooth consumption, leading to a decrease in the return volatility and risk premium of the new asset and a substantial increase in its price.

The main contribution of our work is to show that the traditional view depends crucially on the assumption of homogeneous beliefs; that is, the new (inexperienced) investors need to have the same knowledge about the asset class they gain access to as the (experienced) investors who have been invested in it for some years already. However, if inexperienced investors are less well informed about the new asset class but rationally learn about it,[2] many of these "intuitive" results are reversed and match more closely what we observe empirically: Financial innovation can *increase* return volatility and the risk premium of the new asset—even though it allows for a better sharing of the risks associated with the new asset—and both quantities decline to their pre-innovation levels only slowly over several decades.

[1]These new asset classes include hedge funds, private equity (buyout, venture, distressed), private placement (in public equity and catastrophe bonds), emerging-market equity and debt, mezzanine and distressed debt, real estate (commercial and timberland), infrastructure, natural resources, art and other collectibles, commodities, and precious metals.

[2]The difficulties in assessing new asset classes are discussed by: Phalippou (2009), Phalippou and Gottschalg (2009), and Ang and Sorensen (2013) for private equity; Dhar and Goetzmann (2005) for real estate; and Ang, Ayala, and Goetzmann (2014) for hedge funds and private equity. For evidence on how experience with new asset classes affects investment behavior, see Blackstone (2016, p. 11).

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In order to understand the economic mechanisms through which financial innovation influences asset prices, we study a dynamic general-equilibrium economy that explicitly accounts for financial innovation and provides an internally consistent framework in which the asset-allocation decisions of investors incorporate the feedback effects from prices. In our model, there are three asset classes: a risk-free bond and two risky assets—a traditional asset class representing publicly traded equities and a new asset class. There are two groups of investors with identical recursive preferences. Initially only one group of investors, called "experienced investors," has access to the new asset class. We define *financial innovation* as the process through which the other group of investors—"inexperienced investors"—gains access to the new asset class and we examine the behavior of asset prices at and after financial innovation. In the model, heterogeneous beliefs arise because inexperienced investors are uncertain about the expected growth rate of the new asset's cash flows, but rationally learn about it from observing realized cash-flow shocks once the new asset has been introduced. In contrast, experienced investors, who have been holding this asset for several years, are assumed to know the expected growth rate of the new asset's cash flows.[3]

The model yields many surprising predictions about the impact of financial innovation on asset prices. To understand the changes induced by financial innovation, we start by noting that *before* financial innovation gives inexperienced investors access to the new asset, the portfolios of both groups of investors are highly concentrated: Inexperienced investors overweight the traditional asset, while experienced investors hold all of the new asset. Moreover, inexperienced investors invest in the risk-free bond because not having access to the new asset implies that they bear more risk than experienced investors, and therefore, the precautionary-savings motive is stronger for inexperienced investors.

Upon financial innovation, in the economy with homogeneous beliefs, investors instantly switch to holding a well-diversified portfolio, leading to a decline in the volatility of the average stochastic discount factor. Consequently, the new asset's risk premium

[3]The assumption that experienced investors know the new asset's growth rate is solely for simplicity. Our findings remain unchanged in the more general setting in which experienced investors are less uncertain than inexperienced investors about the new asset's expected dividend-growth rate.

declines substantially because the availability of the new asset to all investors allows for a much better sharing of the risks associated with this asset. At the same time, its return volatility declines slightly. In contrast, with *heterogeneous* beliefs, inexperienced investors' portfolios remain highly concentrated in traditional assets. That is, they tilt their portfolio away from the new asset class because of a negative intertemporal hedging demand, which allows them to protect against downward revisions in the perceived dividend-growth rate of the new asset.[4] Moreover, they continue to invest in the risk-free bond because of their desire for precautionary savings, which now is a consequence of having to learn the expected dividend-growth rate of the new asset. On the other hand, experienced investors have levered positions that overweight the new asset, with both—the leverage and the overweighting—being a consequence of market clearing.

As a result of these asset-allocation decisions, the effect of financial innovation on the volatility of the stochastic discount factor is quite different under heterogeneous beliefs. Because the portfolio of experienced investors is still tilted toward the new asset after financial innovation, the volatility of their stochastic discount factor declines only marginally at the new asset's introduction. At the same time, the combination of parameter uncertainty and rational learning leads to a substantial *increase* in the volatility of the inexperienced investors' stochastic discount factor, so that the volatility of the average stochastic discount factor after financial innovation is *higher* than before financial innovation.

The effect of financial innovation on the new asset's return volatility and its risk premium is also strikingly different under heterogeneous beliefs: the new asset's *return volatility increases* substantially when it becomes available to the inexperienced investors because rational learning *amplifies* the effect of fluctuations in the dividends of the new asset. Specifically, positive cash-flow news implies an upward revision in the perceived dividend-growth rate, and accordingly, inexperienced investors dynamically allocate more

[4]Inexperienced investors wish to hold a portfolio that performs well when marginal utility is high or, equivalently, the new asset's perceived growth rate is low. This is achieved through a negative intertemporal hedging position in the new asset because its return is positively correlated with the perceived growth rate.

capital to the new asset, which leads to a higher price-dividend ratio if they have a preference for early resolution of uncertainty, thus increasing its return volatility. This increase in return volatility, together with the higher volatility of the stochastic discount factor, leads to an additional risk premium for the new asset class. However, the increase in the risk premium is smaller than the increase in return volatility, so that the Sharpe ratio of the new asset declines upon financial innovation. Thus, the new asset, which seemed particularly promising prior to financial innovation, performs relatively poorly after financial innovation so that late entrants into new assets do not earn the same rewards as experienced investors. Moreover, because of the initial increase in the new asset's risk premium (and thus its expected return) in the presence of heterogeneous beliefs, the increase in the price-dividend ratio of the new asset is quite small when it is introduced to inexperienced investors. This is in stark contrast to the substantial increase in the price-dividend ratio under homogeneous beliefs, driven by improved risk sharing.

The results described above—the portfolio concentration of experienced and inexperienced investors and the resulting increase in return volatility and risk premium of the new asset—last for several decades. These quantities decline only slowly over time, as the inexperienced investors' estimate of the dividend-growth rate becomes more precise.

In addition to higher cash-flow uncertainty, a second key feature of new asset classes is their illiquidity relative to traditional assets.[5] We model this by introducing a transaction cost for the new asset, which reduces the frequency with which investors rebalance their holdings in the new asset, thereby further reducing the diversification benefits from investing in the new asset class.[6] Moreover, investors use the more liquid traditional asset as a substitute for trading the new asset. As a consequence, positive (negative) cash-flow news about the *new* asset class strengthens (reduces) demand for the *traditional* asset, leading to a spillover of shocks from the new asset class to the traditional one. This

[5] The substantial costs for trading alternative asset classes is well documented in the literature. Collett, Lizieri, and Ward (2003) estimate transaction costs of over 3% for institutional real estate, Beber and Pagano (2013) find that bid-ask spreads for small-cap firms can be as high as 10%, and costs of private-equity transactions can exceed even 10% (Preqin Special Report (2013)).

[6] Ang, Papanikolaou, and Westerfield (2014, Table 1) report that trading in many asset classes is infrequent; e.g., typical holding periods for venture capital and private equity are 3 to 10 years.

increases the correlation between the returns of the two asset relative to the case with zero transaction costs, and illustrates how shocks in illiquid markets can be transmitted to liquid markets.[7]

Many of the predictions of our model with heterogeneous beliefs are consistent with empirical findings. For example, Goetzmann and Oster (2012) document that "experienced investors," such as the endowments of Yale, Princeton, and Harvard universities, invest a substantial proportion of their endowments in "new" asset classes—about 30% in private equity and 20% in hedge funds—while the average university endowment holds less than 2% in these assets (Brown, Garlappi, and Tiu (2010)). Evidence on the gradual increase—over several *decades*—in the allocation to new asset classes is provided by Lerner, Schoar, and Wang (2008) and Cejnek, Franz, Randl, and Stoughton (2014) for private endowments and for pension funds by Towers Watson (2011). Lerner, Schoar, and Wang (2008) also report that funds that entered earlier into new assets achieved higher returns, while Andonov (2014) and Dyck and Pomorski (2014) find that investors with substantial private equity investments perform significantly better than investors with small investments.

Our paper is related to four strands of the literature. First, we consider the theoretical literature on financial innovation. Simsek (2013a) focuses on its impact on portfolio risks and shows that, in the presence of heterogeneous beliefs, portfolio risks can increase for two reasons: one, investors take on new bets, and two, they increase the magnitude of their existing bets. We highlight a third channel that causes an amplification of portfolio risks: an endogenous increase in the new asset's return volatility. Simsek (2013b) considers the case in which financial innovation leads to a reduction in transaction costs and shows that, with heterogeneous beliefs, traders' portfolio risks might increase as well. Iachan, Nenov, and Simsek (2016) show that access to new risky assets, together with heterogeneous beliefs, induces investors to save more, which, in turn, can explain the decline in returns of various asset classes over the last few decades. We demonstrate that in a dynamic general-equilibrium setting, the implications of financial innovation are

[7] For another model with contagion—an increase in return correlation—see Kyle and Xiong (2001).

even more complex and surprising. That is, return volatilities and risk premia *increase* before they slowly converge to their (lower) long-term levels.[8] We also incorporate rational learning, which, in the presence of recursive preferences, strongly *amplifies* the impact of cash-flow shocks and has important implications for asset prices and returns. Gennaioli, Shleifer, and Vishny (2012) focus on the security-issuance aspect of financial innovation in a model with investors who have a preference for safe cash-flow patterns and biased beliefs (due to neglected risk); in their model, financial intermediaries cater to investors' preferences and beliefs, leading to excessive issuance and, in the long-run, fragile markets.[9]

Second, our work is related to the literature on rational learning in general equilibrium. In a comprehensive analysis, Collin-Dufresne, Johannes, and Lochstoer (2016a) show that parameter learning strongly amplifies the impact of macro shocks when a representative investor has a preference for early resolution of uncertainty. In our paper, the focus is on the *interaction* between rational learning and financial innovation. Thus, in contrast to their model, we consider an economy with multiple risky assets—a traditional asset and a new asset class—with parameter uncertainty about only the new asset's expected dividend-growth rate. Moreover, in our model there are two groups of investors with *heterogeneous beliefs*. Interestingly, even though learning in our model is only for a fraction of aggregate consumption, that represented by the new asset class, and for a fraction of investors—those who are inexperienced—we find that it still has substantial effects on asset prices, which strengthens the findings in Collin-Dufresne, Johannes, and Lochstoer (2016a).[10]

[8]This dynamic process of financial innovation, in combination with rational learning, shares similarities with Pástor and Veronesi (2012), who study the impact of new government policies on stock prices ("announcement returns") when a representative investor faces uncertainty about government policies.

[9]For an extensive discussion of a broader set of issues related to financial innovation, see Merton (1992), Allen and Gale (1994), and the World Economic Forum Report (2012).

[10]Collin-Dufresne, Johannes, and Lochstoer (2016b) and Ehling, Graniero, and Heyerdahl-Larsen (2017) study parameter uncertainty with *biased learning*. Barberis, Greenwood, Jin, and Shleifer (2014) study asset pricing with biased beliefs, resulting from the extrapolation of past price changes. Earlier papers on parameter learning in single-agent settings with time-separable utility include Detemple (1986), David (1997), Veronesi (2000), David and Veronesi (2002, 2013), and Pástor and Veronesi (2003, 2012). For a comprehensive review of this literature, see Pástor and Veronesi (2009).

Third, our work is related to the literature on heterogeneous investors and portfolio constraints. Chabakauri (2015) studies the effect of a limited-participation constraint, limiting one group of investors to invest only a small fraction of wealth in stocks. He demonstrates that this leads to a higher market price of risk in order to compensate unconstrained investors for holding more stocks to clear the market, and excess volatility. Hong, Scheinkman, and Xiong (2006) study the impact of a change in asset float (tradeable shares) on asset prices, documenting that volatility and prices increase when fewer shares become available. Other work includes, among others, Basak and Cuoco (1998), Basak and Croitoru (2000), Gallmeyer and Hollifield (2008), Prieto (2013), and Chabakauri (2013). In contrast to these papers, the focus in our paper is on financial innovation, which can be interpreted as the relaxation of the constraint on the portfolio of inexperienced investors. In particular, we show that in the presence of heterogeneous beliefs, many of the results about asset prices and returns from models that assume homogeneous beliefs can be reversed. Our paper also contributes to this literature by allowing for parameter uncertainty and rational learning.

Fourth, there are several papers that study the effect of heterogeneous beliefs absent portfolio constraints; for instance, Harrison and Kreps (1978), Detemple and Murthy (1994), Zapatero (1998), Scheinkman and Xiong (2003), Dumas, Kurshev, and Uppal (2009), and Xiong and Yan (2010). In contrast to these papers, in which investors have risk-neutral or time-additive preferences, we incorporate recursive preferences, in the presence of which parameter learning leads to an additional risk premium and excess volatility. Moreover, our focus is on the changes in the dynamics of the assets' returns over time, and the interaction between heterogeneous beliefs and financial innovation.

The rest of the paper is organized as follows. In Section 2, we describe the baseline model of the economy we study, equilibrium in this economy, and our solution approach. In Section 3, we analyze the effect of financial innovation on portfolio positions, consumption policies, and return moments. Section 4 summarizes the insights from our robustness analysis, including the results from various extensions of the baseline model. Section 5 concludes. Technical details are relegated to the Appendix.

2 A Model of Financial Innovation

In this section, we describe the general-equilibrium model that we use to study the impact of financial innovation on asset prices. Our modeling assumptions are motivated by the desire to have the simplest possible setup that allows one to understand the effects of financial innovation when investors have heterogeneous beliefs; in Section 4, we discuss various generalizations of this baseline model.

The model is set in discrete time with time interval Δ_t and a finite horizon T; that is, $t \in \{0, 1, \ldots, T\}$. The key feature of the economy is that it is populated by two groups of investors who differ in their access to financial assets. The first group, experienced investors, can invest in all three assets that are available: a risk-free bond, a traditional risky asset, and the new asset class. The second group, inexperienced investors, can initially trade only in the risk-free bond and the traditional risky asset; they gain access to the new asset class only after *financial innovation*. Moreover, inexperienced investors are uncertain about its expected dividend-growth rate and *rationally learn* about it over time. We describe the details of our model below.

2.1 Economic Framework

Investors: The two groups of investors, indexed by $k \in \{1, 2\}$, are assumed to have identical Epstein and Zin (1989) and Weil (1990) preferences over consumption $C_{k,t}$ of the single consumption good.[11] Specifically, lifetime utility $V_{k,t}$ is defined recursively as

$$V_{k,t} = \left[(1-\beta)\, C_{k,t}^{1-\frac{1}{\psi}} + \beta E_t^k \left[V_{k,t+1}^{1-\gamma} \right]^{\frac{1}{\phi}} \right]^{\frac{\phi}{1-\gamma}}, \qquad (1)$$

where E_t^k denotes the time-t conditional expectation under an investor's subjective probability measure, β is the rate of time preference, $\gamma > 0$ is the coefficient of relative risk aversion, $\psi > 0$ is the elasticity of intertemporal substitution (EIS), and $\phi = \frac{1-\gamma}{1-1/\psi}$.

[11] It would be straightforward to allow for heterogeneity in investors' preferences; we assume identical preferences so that we can focus on the effects of financial innovation with heterogeneous beliefs.

Financial Assets: There exist three financial assets. The first asset is a risk-free single-period discount bond in zero net supply, indexed by $n = 0$. In addition, there are two risky assets, each in unit supply, indexed by $n \in \{1, 2\}$. Each of these risky assets is modeled as a claim to the dividend stream, $D_{n,t}$, of a Lucas (1978) tree. Specifically, we assume that, for each tree, log dividend growth $\Delta d_{n,t+1} \equiv \ln\big[D_{n,t+1}/D_{n,t}\big]$ can be described by an IID Normal model with expected dividend-growth rate μ_n and dividend-growth volatility σ_n:

$$\Delta d_{n,t+1} = \mu_n + \sigma_n \, \varepsilon_{n,t+1}, \tag{2}$$

where $\varepsilon_{n,t+1} \sim \mathcal{N}(0, 1)$, and $\varepsilon_{1,t+1}$ and $\varepsilon_{2,t+1}$ are assumed to be uncorrelated.[12] We interpret the first risky asset as a traditional asset that has been available to all investors for some time already, for example, public equity, whereas the second risky asset represents a new asset class. For our main analysis, we assume that all financial assets are perfectly liquid; that is, they can be traded without incurring costs. However, in Section 4, we also consider the case in which the new asset is illiquid.

Financial Innovation: Experienced investors can always trade all three financial assets. In contrast, we assume that inexperienced investors can trade only the risk-free bond and the traditional risky asset until date $t = \tau - 1$. The new asset class becomes available to inexperienced investors only if *financial innovation* occurs. Specifically, we assume that at time $t = \tau$, the new asset is made available to inexperienced investors with probability p, in which case the variable that indicates whether or not financial innovation has occurred is set to $\mathcal{I}_\tau = 1$. One can think of our framework as a setting in which a subset of sophisticated experienced investors has access to a new asset class before it becomes available to the rest of the investors; for example, for many recently introduced asset classes, such as private equity, venture capital, hedge funds, and commodities, initially only a fraction of investors were able to participate.

[12] Even though the dividends are uncorrelated, the asset returns, which depend on equilibrium prices, will be correlated. A detailed description of the economic mechanism that drives this correlation is given in footnote 28. In one of our extensions of the baseline model, we allow for correlated dividends and find that our results remain unchanged.

Note that, for ease of exposition, in the base-case of our model we consider a simplified framework for financial innovation in which date τ is exogenous and known to all investors. In practice, the introduction of a new asset would be undertaken by financial intermediaries whose decision would depend on the demand for the new asset. Therefore, in Section 4, we consider other settings where the timing and introduction of the new asset are determined endogenously and demonstrate that the insights from our simplified framework remain unchanged in these more general cases.[13]

2.2 Learning

For ease of exposition, we assume that experienced investors have perfect knowledge of the new asset's dividend dynamics and also that both groups of investors fully understand the dynamics of the dividends of the traditional asset.[14] In contrast, we assume that when inexperienced investors gain access to the new asset class, these investors are less well informed about the new asset than experienced investors, who had been holding the asset until then. That is, inexperienced investor faces parameter uncertainty and have to learn about the dynamics of the new asset class.[15]

Specifically, we assume that inexperienced investors know the dividend-growth volatility of the new asset, σ_2, but are uncertain about its expected dividend-growth rate, μ_2, and at date τ have the prior $\mu_2 \sim \mathcal{N}(\mu_{2,\tau}, A_\tau\, \sigma_2^2)$.[16] Starting from this prior, inexperienced investors use realized dividend growth to update their beliefs about its expected growth

[13]One could study the effect of financial innovation in a variety of ways. For instance, one could compare two economies: one in which the new asset is unavailable to inexperienced investors and another in which it is available; the disadvantage of this approach is that it fails to capture the transition dynamics when the new asset becomes available. Alternatively, financial innovation could be modeled by making the new asset available in a non-stochastic way to new investors at a predetermined date; the disadvantage of this approach is that investors would perfectly anticipate the introduction of a new asset, which is unrealistic.

[14]The model can be extended in a straightforward way to incorporate generalizations, such as parameter uncertainty for both investors and/or parameter uncertainty about both risky assets. Also, one could allow inexperienced investors to learn about the new asset class starting from date $t = 0$ instead of $t = \tau$, even though the new asset becomes available for trading only at date τ. The results in these cases are similar.

[15]There is substantial empirical evidence about the difficulties in assessing a new asset class because of limited data and investor inexperience; see footnote 2.

[16]$A_\tau \sigma_2^2$ represents the reciprocal of the prior precision, so that the prior density converges to a uniform distribution as A_τ approaches infinity and converges to a single value as A_τ approaches zero.

rate using Bayes' rule. In particular, the prior, combined with the dividend dynamics in (2), implies a time-t posterior density function $p(\mu_2|d_2^t) = \mathcal{N}(\mu_{2,t}, A_t\,\sigma_2^2)$, where d_2^t denotes the history of all observed dividend-growth realizations up to time t: $d_2^t = \{\Delta d_{2,s}\}$, $s \in \{\tau, \ldots, t\}$, $t \geq \tau$ and the dynamics of $\mu_{2,t}$ and A_t are described by

$$\mu_{2,t+1} = \mu_{2,t} + \left(\Delta d_{2,t+1} - \mu_{2,t}\right) \frac{A_t}{1 + A_t}, \tag{3}$$

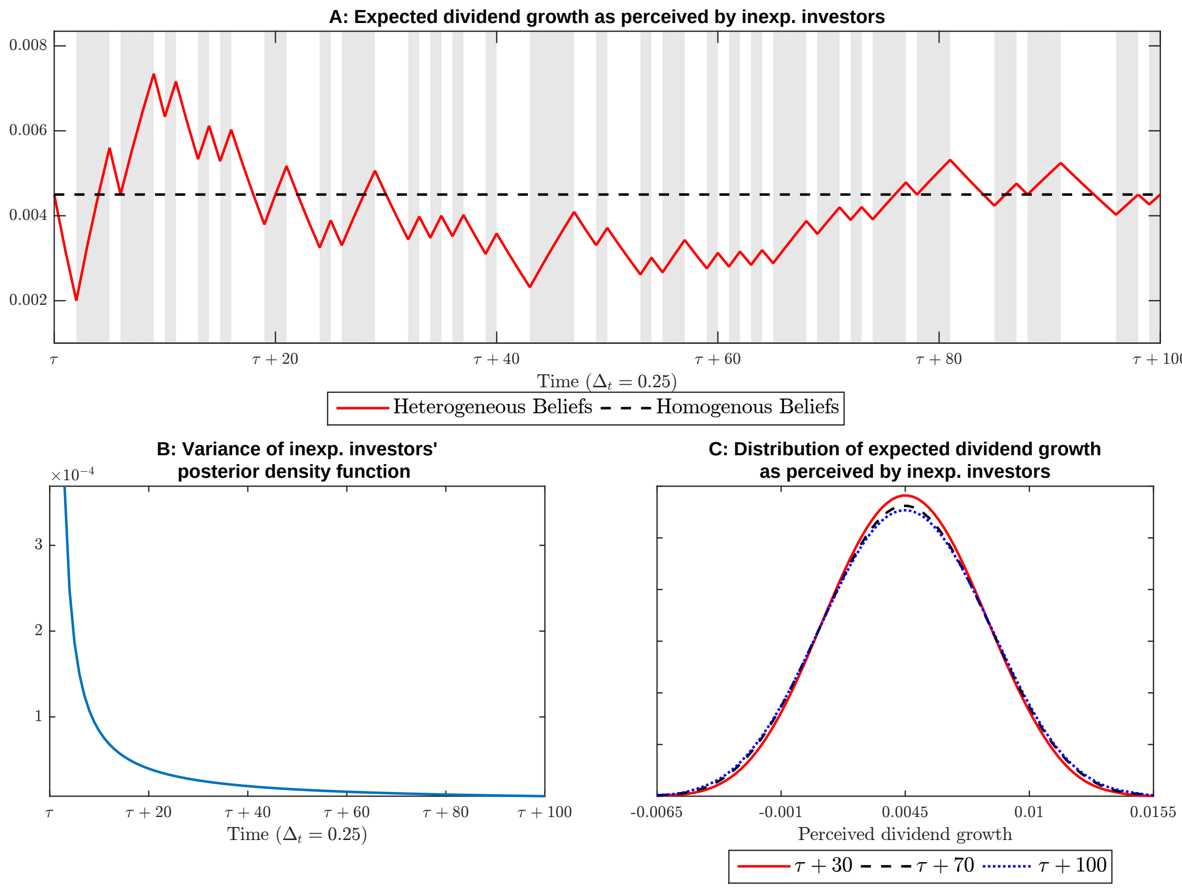
$$A_{t+1} = \frac{1}{1/A_t + 1}. \tag{4}$$

Consequently, even though the dividend dynamics of the new asset are driven by an IID model with constant parameters, from the perspective of inexperienced investors the expected dividend-growth rate $\mu_{2,t}$ is time-varying: equation (3) shows that positive cash-flow news leads to an upward revision of the perceived dividend growth and vice versa for negative cash-flow news. In particular, dividend-growth shocks lead to permanent shifts in the perceived mean dividend growth because $\mu_{2,t+1}$ is a martingale. This is illustrated in Panel A of Figure 1 that plots, for a simulated path of the economy, the expected dividend-growth rate of the new asset as perceived by the inexperienced investors. One can observe that positive dividend-growth shocks, highlighted in shaded gray, lead to an upward revision of the perceived dividend-growth rate, and negative shocks lead to a downward revision.

Panel B of Figure 1 shows that the posterior variance $A_t\,\sigma_2^2$ converges deterministically to zero, because A_t in (4) converges to zero. This implies ever smaller rational updates to the perceived growth rate over time, because the impact of the realized dividend growth $\Delta d_{2,t+1}$ on $\mu_{2,t+1}$ declines as A_t declines. Hence, the investor's perceived growth rate converges in the long run—though not necessarily to the true value μ_2. Panel C shows the probability density function of the new asset's expected dividend-growth rate as perceived by the inexperienced investors, $\mu_{2,t}$, for different dates. One can observe substantial variation in the investors' beliefs after 30 quarterly observations. The distribution converges quickly, being very similar after 30, 70, and 100 quarterly

Figure 1: Learning

This figure illustrates rational learning in our model. Panel A depicts the dividend-growth rate for the new asset, as perceived by inexperienced investors, for a simulated path of the economy. The shaded gray areas indicate periods of positive dividend realizations for the new asset, which lead to an upward revision in its perceived growth rate. Panel B shows the (deterministic) decline in the variance of the inexperienced investors' posterior, $A_t\sigma_2^2$, over time. Panel C shows the distribution of the expected dividend growth rate of the new asset as perceived by the inexperienced investors, $\mu_{2,t}$ after the elapse of 30, 70, and 100 periods. This figure is based on the following parameter values: $\Delta_t = 1/4$, $\mu_{2,\tau} = 0.0045$, $A_\tau = 20$, and $\sigma_2 = 0.0275$.



observations and is always nicely centered around the true mean but even after 100 quarters there is substantial variance.

The stochastic nature of $\mu_{2,t}$ implies that the difference in the beliefs of the two groups of investors is fluctuating over time, with investors in one group sometimes being more optimistic and at other times being more pessimistic than investors in the other group.

However, over time these fluctuations diminish because the updates to the beliefs of the inexperienced investors become smaller as their precision increases.

2.3 Investors' Optimization Problem and Equilibrium

The objective of investors in group k is to maximize their expected lifetime utility given in equation (1), by choosing their consumption, $C_{k,t}$, and their holdings in the available financial assets, $\theta_{n,k,t}, n \in \{0, \ldots, N_{k,t}\}$. In particular, while experienced investors always have access to both risky assets ($N_{1,t} = 2, \forall t$), inexperienced investors initially have access to only the traditional risky asset ($N_{2,t} = 1, t < \tau$) and gain access to the second risky asset only if financial innovation occurs ($N_{2,t} = 2$ if $\mathcal{I}_\tau = 1, t \geq \tau$). This optimization is subject to the budget equation

$$C_{k,t} + \theta_{k,0,t}\, S_{0,t} + \sum_{n=1}^{N_{k,t}} \Delta\theta_{k,n,t}\, S_{n,t} \;\leq\; \theta_{k,0,t-1} + \sum_{n=1}^{N_{k,t}} \theta_{k,n,t-1}\, D_{n,t}, \tag{5}$$

where $\Delta\theta_{k,n,t}$ denotes the change in the shares held of asset n and $S_{n,t}$ denotes the price of asset n. The left-hand side of budget equation (5) describes the amount allocated to consumption, the purchase or sale of the (newly issued) short-term bond, and changes in the portfolio positions in the risky assets. The right-hand side reflects the available funds, stemming from the unit payoff of the (old) short-term bond as well as the dividends from the holdings of the available risky assets.

Equilibrium in the economy is defined as a set of consumption and asset-allocation policies, along with the resulting price processes for the financial assets such that the consumption policies of all investors maximize their lifetime utility, that these consumption policies are financed by the asset-allocation policies that investors choose, and that markets for the financial assets and the consumption good clear.

2.4 Solving for the Equilibrium

If financial markets are *complete*, one can separate the task of identifying the equilibrium into two distinct steps by exploiting the condition that investors can achieve perfect risk sharing. This condition can be exploited to first identify the optimal allocation of aggregate consumption across investors, and then, in the second step, one can determine asset prices and also the portfolio policy of each investor that supports this consumption allocation.

Instead, in economies in which financial markets are *incomplete*, such as the one considered here, one must solve *simultaneously* for the consumption and investment policies of the two groups of investors along with asset prices, leading to an equation system that requires backward and forward iteration in time, instead of a purely recursive system. Dumas and Lyasoff (2012) show how the backward-forward system of equations can be reformulated to obtain a purely recursive system, using a "time shift" for a subset of the equations that characterize the equilibrium. We solve for the equilibrium numerically, extending the algorithm proposed by Dumas and Lyasoff (2012) to the case of parameter uncertainty with rational learning, multiple risky assets, and Epstein-Zin-Weil utility functions. Details of our approach are given in the Appendix.

3 Effects of Financial Innovation

In this section, we illustrate the impact of financial innovation on the dynamics of the investors' asset allocation decisions, their consumption policies, and the resulting effect on the stochastic discount factors and the dynamics of asset prices and returns. We conclude with a brief discussion of the welfare effects of financial innovation.

3.1 Parameter Values

The parameter values used in our numerical illustrations are summarized in Table 1. We solve the model at a quarterly frequency ($\Delta_t = 1/4$ years) for $T = 800$ periods, for a total of 200 years. The distant terminal date minimizes any effects resulting from the finite horizon. The results reported below are based on $50,000$ simulations of the economy. We assume that the inexperienced investors might get access to the new asset at time $\tau = 40$ (that is, after 10 years) with probability $p = 0.50$.

Table 1: Model Parameters

This table reports the parameter values used for our numerical illustrations. The choice of these parameter values is explained in Section 3.1.

Variable	Description	Base Case
Δ_t	Trading (and observation) interval	1/4 year
T	Total number of trading dates (quarters)	800
τ	Date of introduction of the new asset (quarter)	40
p	Probability of introduction of the new asset	0.50
β	Rate of time-preference per quarter	0.993
γ	Relative risk-aversion	10
ψ	Elasticity of intertemporal substitution	1.50
$w_{2,0}$	Initial wealth share of the inexperienced investors	2/3
μ_n	Expected dividend growth per quarter	0.45%
σ_n	Dividend growth volatility per quarter	2.75%
ρ	Correlation between dividend growth rates	0
$\delta_{1,0}$	First asset's share of total initial dividends	0.80
λ	Leverage factor	2.5
$\mu_{2,\tau}$	Initial mean of inexperienced investor's prior distribution	0.45%
A_τ	Initial precision of inexperienced investor's prior distribution	20
$\underline{\mu}_2, \bar{\mu}_2$	Truncation boundaries for beliefs of inexperienced investors	$[-0.65\%, 1.55\%]$

For the preference parameters, we use a (quarterly) rate of time-preference $\beta = 0.993$, a coefficient of relative risk-aversion, $\gamma = 10$, and an elasticity of intertemporal substitution $\psi = 1.5$—common choices in the literature (see, for instance, Bansal and Yaron (2004) and Collin-Dufresne, Johannes, and Lochstoer (2016a)).

We assume that at time $t = 0$, inexperienced investors are endowed with 2/3 of the total wealth, as it seems reasonable that initially a majority of investors does not participate in the new asset class. The initial wealth of the inexperienced investors is fully concentrated in the market portfolio; that is, they do not have any debt and are not endowed with any shares of the new asset class. On the other hand, experienced investors hold all the shares of the new asset class with the rest of their wealth in the traditional risky asset; they, too, start out with zero debt.

For both trees, $n \in \{1, 2\}$, we set the expected dividend-growth rate μ_n to 0.45% per quarter and the corresponding volatility σ_n to 2.75% per quarter, with the correlation between the dividends being equal to zero.[17] Together with an initial dividend share of the first tree, $\delta_{1,0}$, of 0.80,[18] this implies an expected growth rate of aggregate consumption of 1.80% per year and a time-average annual aggregate consumption growth volatility of 3.73%.[19] When computing the returns of the claims to the dividend trees we apply a leverage factor of $\lambda = 2.5$ to accommodate the fact that most assets are implicitly levered—a common assumption in the literature—Collin-Dufresne, Johannes, and Lochstoer (2016a, p. 21) use a value of 2.5 and Bansal and Yaron (2004, Table II) use a value of 3.

We set the mean of the inexperienced investors' prior distribution, $\mu_{2,\tau}$, equal to the true expected dividend-growth rate μ_2, leading to, on average, unbiased beliefs. The parameter governing the initial precision, A_τ, is set to 20 and we truncate the inexperienced investors' beliefs at $\underline{\mu}_2 = -0.65\%$ and $\bar{\mu}_2 = 1.55\%$.[20] In the figures below that are used to illustrate our results, in addition to this case of *heterogeneous beliefs*, we also always report the results for the case of *homogeneous beliefs*; that is, for the case in which both groups of investors know the true growth rate of the new asset.

[17] The choice of equal means and volatilities for the two dividend trees guarantees a stable mean dividend share over time. Thus, we abstract from any effects arising from a drift in the mean dividend share. Note, however, that in the long-run one approaches a bimodal distribution with dividend shares of zero and one—a standard result for such models; see, for example, Cochrane, Longstaff, and Santa-Clara (2008). While this might pose some problems for a long-term analysis, it is less important for our analysis, because our focus is on the transitional dynamics for the initial years following financial innovation. In fact, even after 100 years, the distribution is well behaved.

[18] The market capitalizations implied by a long-term mean dividend share for the new asset class of 20% are realistic for a variety of asset classes. For example, assets under management for private equity and hedge funds are about \$3.5 and \$1.7 trillion, respectively—relative to \$18 trillion for U.S. stock-market capitalization.

[19] These numbers are close to the annual time-averaged mean and volatility of U.S. per capita consumption growth of 1.72% and 3.28% from 1889 to 1994. The higher consumption-growth volatility is required to get a reasonable equity risk premium.

[20] Accordingly, we use a truncated Normal prior for μ_2, which results in a posterior that is truncated Normal with the same truncation bounds as the prior. Conveniently, the updating equations for the hyperparameters, $\mu_{2,t+1}$ and A_{t+1} remain the same. Only 0.25% of the simulated paths of the economy hit the truncation bounds at some point prior to $t = 140$. Truncation is needed for an elasticity of intertemporal substitution that differs from one, to guarantee the existence of equilibrium (see the discussion in the online appendix of Collin-Dufresne, Johannes, and Lochstoer (2016a)). In Section 4, we document that the effect of the truncation bounds is negligible and that the choice of initial precision, A_τ, has no effect on the qualitative results.

3.2 Asset Allocation

We start by studying the asset allocation decisions of the two groups of investors. Figure 2 shows the dynamics of the investors' portfolio shares, that is, the proportion of the investors' wealth allocated to each of the three financial assets.

First, note that *before* the introduction of the new asset at time $\tau = 40$, the portfolios of both groups of investors are basically the same across the cases of homogeneous beliefs and heterogeneous beliefs; that is, in all the panels of Figure 2, the two lines coincide for dates $t < 40$. However, there are large differences in the portfolios of experienced and inexperienced investors. Neither group of investors holds the market portfolio.[21] Inexperienced investors are overinvested in the traditional asset (Panel E) because they do not have access to the new asset; in contrast, experienced investors are overinvested in the new asset (Panel D), because the inexperienced investors have no access to this asset. Therefore, the risky parts of the portfolios of both groups of investors are *more volatile* than if all investors had access to the new asset.

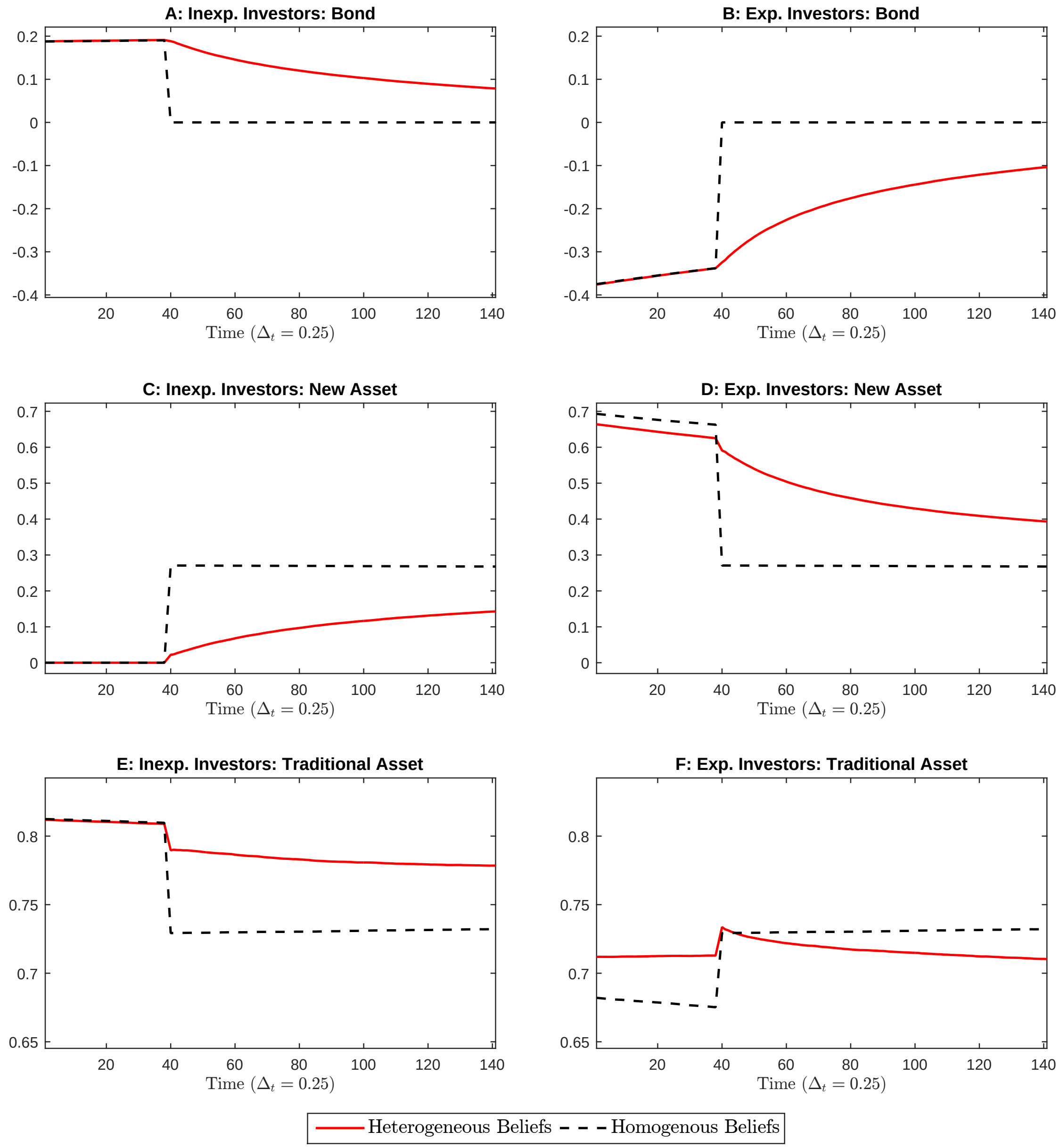
In the presence of this market incompleteness, the resulting additional "background" risk leads to a precautionary-savings motive from both investors. However, because inexperienced investors have no access to the new asset and therefore bear more risk than experienced investors, they have a stronger precautionary-savings motive. Consequently, in equilibrium, the portfolios of inexperienced investors consist of a constant fraction of their wealth invested in the risk-free bond (Panel A of Figure 2), with their remaining wealth invested in the traditional asset (Panel E). On the other hand, the portfolio of experienced investors consists of a short position in the risk-free bond (Panel B) and long positions in the two risky assets (Panels D and F).

After the introduction of the new asset at date $\tau = 40$, the portfolios of the two groups of investors differ substantially across the cases of homogeneous and heterogeneous beliefs. In the case of homogeneous beliefs, that is, when inexperienced investors are assumed

[21] The weights in the market portfolio are simply equal to the relative size, measured by market capitalization, of the two risky assets. Specifically, in our setting, they are equal to about 73% and 27% for the traditional and the new asset, respectively.

Figure 2: Asset Allocation

This figure shows the evolution of the portfolio shares over time of the inexperienced investors (left column) and experienced investors (right column), averaged across simulation paths, based on the parameter values described in Section 3.1. Panels A and B show the average proportion of the wealth invested in the risk-free bond for the inexperienced and experienced investors, Panels C and D the average proportion of wealth invested in the new asset, and Panels E and F the average fraction of wealth invested in the traditional risky asset.



to know the true growth rate of the new asset, both groups of investors have identical portfolios; in particular, they hold the market portfolio and have zero position in the risk-free bond. In contrast, if inexperienced investors are uncertain about the dynamics of the new asset class, then the portfolios of the two groups of investors are very different—even though the new asset is now available to all investors—and substantially different from the market portfolio. Inexperienced investors have a positive but declining position in the risk-free bond which, again, is a consequence of their desire for precautionary-savings, now resulting from the additional (background) risk of changing beliefs. Over time, as the posterior variance of the inexperienced investors declines (see Panel B of Figure 1), so does their precautionary-savings motive, and thus, the portfolio share allocated to the bond declines over time (solid line in Panel A of Figure 2).

Observe from Panel C of Figure 2 that as soon as financial innovation gives inexperienced investors access to the new asset class, they invest into it for diversification reasons. However, compared to the case in which they know the true growth rate (dashed line), the investment is rather small in the presence of parameter uncertainty (solid line); this is because of a *negative* intertemporal hedging demand for the new asset in the presence of parameter uncertainty and rational learning. That is, they wish to hold a portfolio that performs well when marginal utility is high or, equivalently, the new asset's perceived growth rate is low. This is achieved through a negative intertemporal hedging position in the new asset because its return is positively correlated with the perceived growth rate. With the decline in the inexperienced investors' posterior variance over time, shocks to the perceived dividend-growth rate also decline, as does the magnitude of the negative hedging demand; accordingly, inexperienced investors gradually increase their holdings in the new asset. But, even twenty-five years after financial innovation (that is, at $t = 140$), inexperienced investors still assign a substantially smaller weight to the new asset relative to experienced investors.

The investment into the new asset class by the inexperienced investors following financial innovation leads to a reduction in the portfolio share of the traditional asset (Panel E of Figure 2). However, because in the presence of learning the investor is underinvested in the new asset, the portfolio share of the traditional asset with heterogeneous beliefs (solid line) still exceeds that for the case of full information (dashed line).

The portfolio shares of the experienced investors in the presence of heterogeneous beliefs follow naturally from the positions of the inexperienced investors. That is, for reasons of market clearing, experienced investors take a short position in the bond, which is (in absolute terms) declining over time (Panel B of Figure 2). Moreover, to clear the markets for the two risky assets, the experienced investor is, even after the new asset becomes available to all investors, overinvested in the new asset (solid line in Panel D) and underinvested in the traditional asset (solid line in Panel E) relative to the case of homogeneous beliefs.

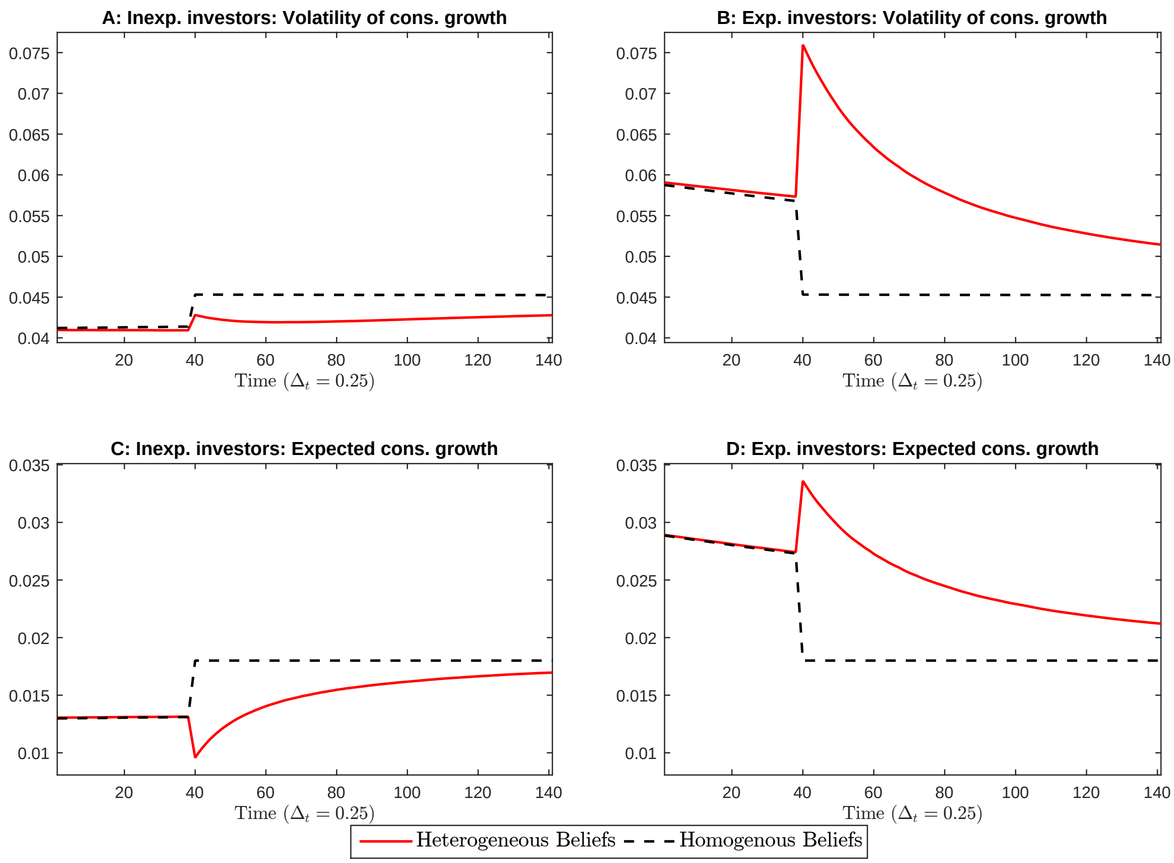
3.3 Consumption Policies

The optimal consumption policies of the two groups of investors, which are determined in equilibrium jointly with investors' asset-allocation choices, are depicted in Figure 3. Similar to the results for portfolio shares, *before* financial innovation occurs, the consumption policies are essentially the same across the cases of homogeneous and heterogeneous beliefs. In particular, the consumption of inexperienced investors is expected to grow more slowly, but is also less volatile than that of experienced investors. Intuitively, the desire for precautionary savings leads inexperienced investors to hold a portfolio that is less risky (a large proportion of wealth invested in the risk-free asset), which allows them to better smooth their consumption across states; in contrast, experienced investors, whose portfolio is levered, have consumption that is more volatile. Of course, this risk-sharing arrangement, in which the experienced investors offer "insurance" to inexperienced investors, needs to be paid for. That is, leverage and the resulting higher expected portfolio return of the portfolio of experienced investors also explains their higher expected consumption growth rate.

After financial innovation makes the new asset available to inexperienced investors, the consumption-growth patterns differ substantially across the cases of homogeneous

Figure 3: Consumption Policies

The figure shows the dynamics of the moments of the consumption policies of inexperienced and experienced investors over time, based on the parameter values described in Section 3.1. Panels A and B show the average conditional consumption growth volatility and Panels C and D the average conditional expected consumption growth.



and heterogeneous beliefs. If the two groups of investors have homogeneous beliefs, investors are identical and, hence, would consume a constant fraction, equal to their wealth share, of aggregate consumption. Therefore, in this case their consumption policies would simply inherit the dynamics of aggregate consumption growth, which leads to a reduction (increase) in the expected consumption growth and its volatility for the experienced (inexperienced) investors.

In contrast, if the two groups of investors have heterogeneous beliefs because the inexperienced investors have to learn about the expected growth rate, then the consumption-growth volatility of *both* groups of investors *increases* upon the introduction of the new asset (solid line in Panels A and B of Figure 3). For experienced investors, the increase is driven mostly by an increase in their portfolio volatility because of a sizable increase in the return volatility of the new asset (discussed in detail below), which is overweighted in their portfolios. This effect dominates the dampening effect from a slightly lower leverage. For inexperienced investors, the increase in consumption-growth volatility stems from smaller precautionary savings and the large investment in the new asset, which now is more volatile. Over time, the decline in leverage and return volatility of the new asset lead to a decline in consumption-growth volatility for both groups of investors. However, the reduction in consumption volatility over time is much less pronounced for inexperienced investors, because the reduction in the new asset's return volatility is offset by smaller precautionary savings that lead to a reduction in the investment in the risk-free bond.

When the new asset becomes available, the expected consumption growth of experienced investors further increases relative to that of the inexperienced investors (Panels C and D of Figure 3). This is a consequence of the higher expected return on the new asset following financial innovation (discussed in detail below).[22] However, the difference between the consumption growth rates declines over time. That is, as a result of the decline in precautionary savings, the difference in the investors' expected portfolio returns narrows, and, in turn, the difference in expected consumption growth rates declines.

3.4 Stochastic Discount Factor

The stochastic discount factor (SDF) of investors in group k, $M_{k,t+1}$, is given by

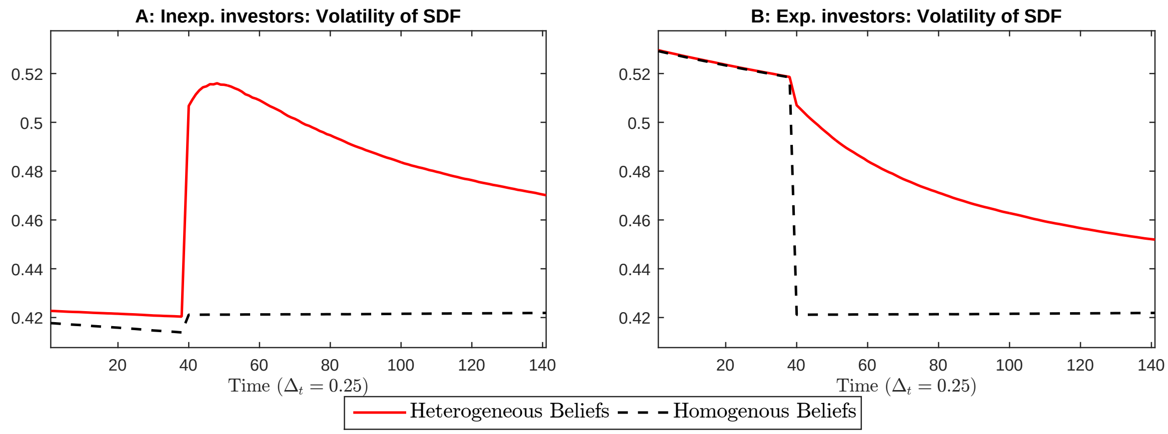
$$M_{k,t+1} = \beta\, \delta_t \, \exp\Big((-1/\psi)\, \Delta c_{k,t+1} - (\gamma - 1/\psi)\, v_{k,t+1} \Big), \tag{6}$$

where $\delta_t = E_t^k \left[\exp\big((1-\gamma)\, v_{k,t+1} \big) \right]^{(\gamma - 1/\psi)/(1-\gamma)}$, $c_{k,t+1}$ denotes log consumption, and $v_{k,t+1}$ denotes the log of lifetime continuation utility. Hence, shocks to the log SDF,

[22] The risk-sharing arrangement between the experienced and inexperienced investors is captured well by Brian Tracy's quote: "When a man with money meets up with a man with experience, the man with the experience is going to end up with the money and the man with money is going to end up with the experience." We are grateful to Francis Longstaff for bringing this quote to our attention.

Figure 4: Stochastic Discount Factors

This figure shows the average conditional volatility of the stochastic discount factor for the inexperienced and experienced investors, based on the parameter values described in Section 3.1.



$m_{k,t+1} \equiv \log(M_{k,t+1})$, can be written as

$$m_{k,t+1} - E_t^k[m_{k,t+1}] = -\,(1/\psi)\left(\Delta c_{k,t+1} - E_t^k[\Delta c_{k,t+1}]\right) \\ -\,(\gamma - 1/\psi)\left(v_{k,t+1} - E_t^k[v_{k,t+1}]\right). \tag{7}$$

Expressing the SDF in terms of these two components makes it clear that, if relative risk aversion is not equal to the reciprocal of EIS ($\gamma \neq 1/\psi$), then shocks to future continuation utility, $v_{k,t+1}$, are a source of priced risk—in addition to shocks to log consumption growth, $\Delta c_{k,t+1}$. In particular, the volatility of the SDF is driven by: (i) consumption growth volatility, (ii) variation in future continuation utility, which is almost exclusively because of variation in posterior beliefs, and (iii) their covariance.

Accordingly, in the case in which both groups of investors know the true growth rate of the new asset's dividends, and thus there is no variation in posterior beliefs, the pattern of the volatility of the SDF matches exactly the pattern for consumption growth volatility (that is, the dashed lines in Panels A and B of Figures 3 and 4): the volatility of the SDF of inexperienced investors increases (slightly) with the introduction of the new asset; in contrast, the volatility of the SDF of experienced investors is higher before the new asset becomes available, but falls at introduction.

On the other hand, if inexperienced investors are uncertain about the true growth rate but learn about it over time, the volatility of the SDF of both groups of investors is *higher* than for the case with homogeneous beliefs in which the growth rate is known. The economic mechanism driving the increase in the volatility of the SDF of inexperienced investors is the second component in (7). In particular, the continuation utility of inexperienced investors is highly sensitive to shocks to the perceived dividend-growth rate of the new asset, because these shocks are permanent.

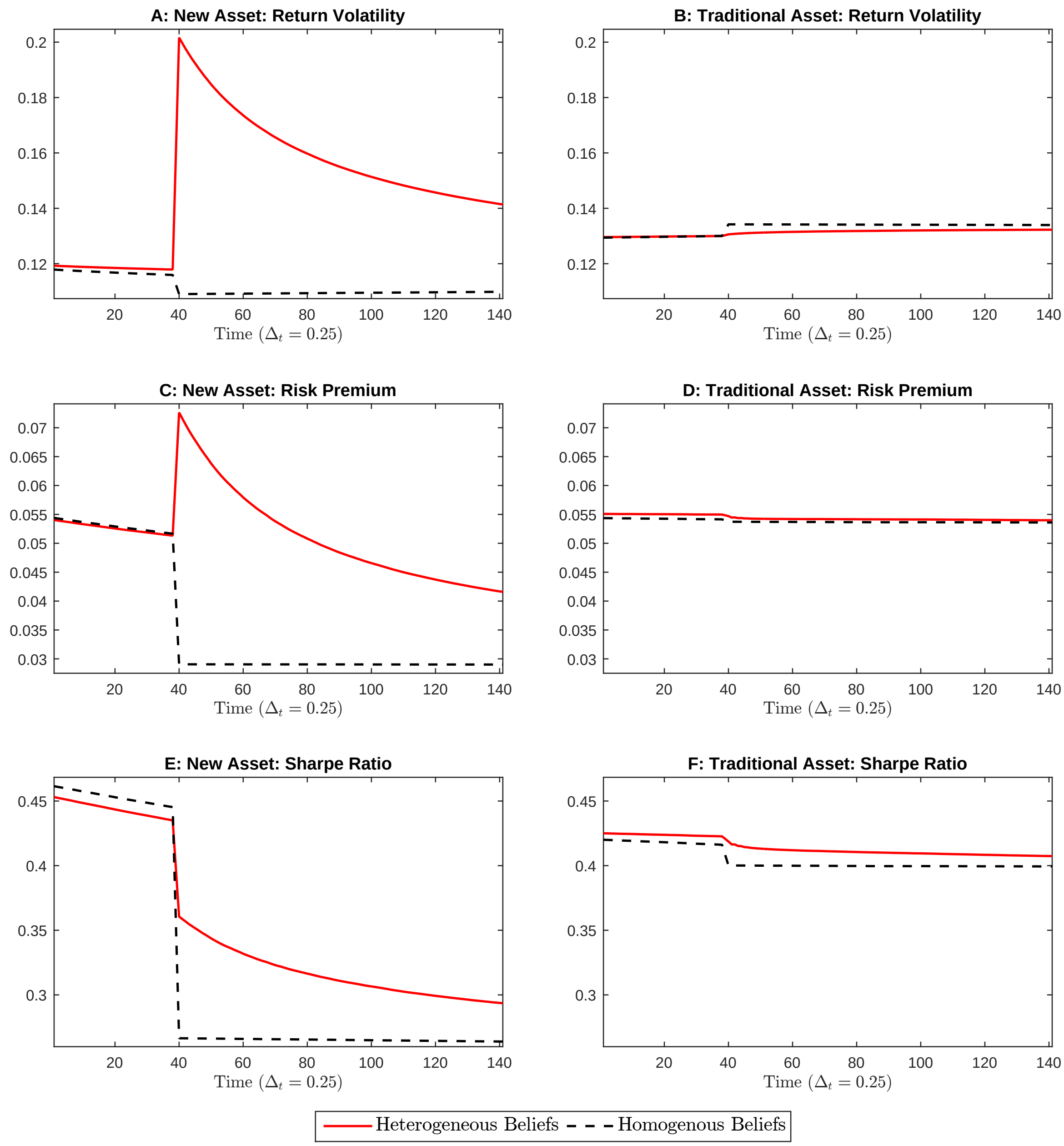
3.5 Moments of Asset Returns

We now focus on a key objective of the paper: to study the implications of financial innovation for asset returns. Figure 5 shows the return moments for the two risky assets in our model. Similar to the results regarding optimal consumption and portfolio policies discussed in the sections above, *before* financial innovation makes the new asset available to inexperienced investors, the average return moments are very similar across the cases of homogeneous and heterogeneous beliefs. Panels A–F in Figure 5 also show that the return moments are very stable until $t = \tau - 1$; this is because the *averages* of the consumption share and the dividend share (which are the only sources of variation during this period) are essentially constant over time.

Turning to the levels of the return volatilities and the risk premia on the two risky assets, we start by highlighting the finding in Cochrane, Longstaff, and Santa-Clara (2008) that in a standard economy in which all investors have access to all assets, assets are symmetric and there is no parameter uncertainty, the risk premium of the asset with the larger dividend share would be higher than that of the other asset. Specifically, because of the larger dividend share, the asset's dividends constitute a larger fraction of aggregate consumption, and thus, co-vary more with it. The return volatility of the larger asset would also typically be slightly higher than that for the asset with the smaller share of aggregate dividends.

Figure 5: Moments of Asset Returns

This figure shows the dynamics of the return moments of the financial assets over time, based on the parameter values described in Section 3.1. Panels A and B show the average conditional return volatilities, Panels C and D the average conditional risk premia, and Panels E and F the average Sharpe ratio of the new asset and the traditional asset, respectively.



In contrast to the result in Cochrane, Longstaff, and Santa-Clara (2008) for a standard economy, in our model prior to financial innovation ($t < \tau$) the risk premium of the new asset, despite having a smaller dividend share, is of the same magnitude as the risk premium for the traditional asset (Panels C and D of Figure 5);[23] this is because, prior to financial innovation, only experienced investors have access to the new asset and therefore they have to bear all of the risk of holding the new asset. At the same time, the pattern for the return volatilities (Panels A and B) is comparable to the results in the standard economy; that is, the volatility is slightly lower for the new asset. Thus, before the new asset becomes available to all investors, the Sharpe ratio of the new asset is *endogenously* higher than that of the traditional asset (Panels E and F).

After financial innovation occurs, there is a dramatic change in the return moments of the new asset, with major differences depending on whether beliefs are homogeneous or heterogeneous. If both groups of investors know the true growth rate of the new asset's dividends, the new asset's risk premium drops substantially (dashed line in Panel C of Figure 5) when it becomes available to inexperienced investors because the risk of holding the new asset is now shared between the two groups of investors, whereas its return volatility is largely unchanged (dashed line in Panel A). Thus, the Sharpe ratio of the new asset *drops substantially* (dashed line in Panel E) at the introduction of the new asset. On the other hand, the return moments of the traditional assets are only marginally affected by the introduction of the new asset (Panels B, D, and F). Hence, in a setting in which the new asset's growth rate is assumed to be known to all investors, the return moments after the introduction resemble very much the results from a standard economy, with the new asset's risk premium and Sharpe ratio being considerably lower—due to its smaller share of aggregate dividends.

In contrast, if inexperienced investors have to learn about the new asset's dynamics, the implications of financial innovation are substantially different and in stark contrast to "conventional wisdom." For example, at the introduction of the new asset, the return volatility of the new asset *increases* considerably (solid line in Panel A of Figure 5) and

[23]The risk premium on the new asset is actually slightly higher than that of the traditional asset.

is much higher than the volatility of the traditional asset, which does not change much at introduction (solid line in Panel B). To understand the reason for the higher return volatility of the new asset, recall that positive (negative) cash-flow news for the new asset class leads to an upward (downward) revision in its perceived dividend-growth rate by inexperienced investors. If the substitution effect dominates the wealth effect, that is, with EIS > 1, these upward (downward) revisions lead to a higher (lower) price-dividend ratio for the new asset class. Accordingly, positive dividend news coincides with a higher price-dividend ratio, and vice versa for negative news, thereby *amplifying* the variations in its dividend and creating "excess volatility." Only over time does the decline in the posterior variance dampen this amplification mechanism, explaining the slow decline in volatility. However, even after 25 years of being introduced (that is, at $t = 140$), the return volatility of the new asset (Panel A) is higher than that of the traditional asset (Panel B).

Similarly, in the case in which inexperienced investors have to learn about the dynamics of the new asset, the new asset's risk premium is *increased* by financial innovation—even though innovation allows the investors to share the risk of holding the asset. To understand the economic mechanism driving this result, note that an asset's risk premium is given by the covariance between its return and the SDF:

$$
\begin{aligned}
E_t[r_{n,t}] - r_{0,t} &= -\mathrm{Cov}_t\big(M_{k,t+1}, r_{n,t+1}\big) \\
&= -\mathrm{Corr}_t\big(M_{k,t+1}, r_{n,t+1}\big)\,\mathrm{Vol}_t\big(M_{k,t+1}\big)\,\mathrm{Vol}_t\big(r_{n,t+1}\big), \qquad (8)
\end{aligned}
$$

where $r_{0,t}$ denotes the risk-free rate and $r_{n,t}$ the return on the asset. With heterogeneous beliefs, both the volatility of the new asset's return and the volatility of the SDF of the "average" investor increase substantially at financial innovation. At the same time, the correlation of the SDF with the new asset's return increases only slightly (that is, it is smaller in absolute terms). Consequently, the risk premium on the new asset increases. Only over time, as the volatility of the SDF and the volatility of the new asset's return decline, so does its risk premium.

Taken together, the stronger increase in the return volatility relative to the increase in the risk premium of the new asset leads to a substantial decline in its Sharpe ratio at the time of financial innovation. Over time, the reduction in the risk premium is stronger than the decline in the return volatility, which causes the Sharpe ratio to decline further. An alternative way to think about the change in Sharpe ratio is that the availability of the new asset to all investors increases aggregate demand for the asset. Thus, because the asset is in fixed supply, its attractiveness for investors must decrease, which is achieved by a drop in its Sharpe ratio. As the posterior variance declines over time, and consequently, the demand strengthens further, this "equilibrium incentive" must also strengthen, implying a further decline in the Sharpe ratio over time.[24]

3.6 Asset Prices

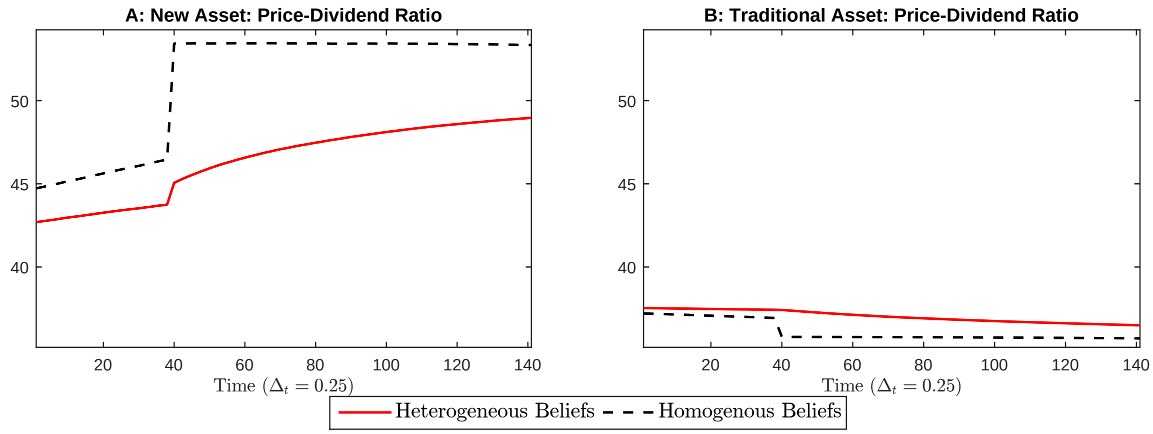
Recall that dividend-growth rates in the model are exogenous and IID, so that price-dividend ratios are driven entirely by discount rates. Hence, the price-dividend ratios are roughly the inverse of the expected returns and can be understood as such.

Upon financial innovation, the price-dividend ratio of the new asset increases (Panel A of Figure 6). Under homogeneous beliefs, the reason for this is that the risk premium on the new asset drops considerably when it becomes available to all investors (see Panel C of Figure 5 and the discussion in Section 3.5), leading to a reduction in the asset's expected return, and consequently, a substantial increase in its price-dividend ratio. In the case with heterogeneous beliefs in which inexperienced investors need to learn about the growth rate of the new asset, the increase in the price-dividend ratio is considerably smaller. In particular, the initial *increase* in the asset's risk premium (which dominates a small reduction in the risk-free rate) dampens the effect of lower long-term expected returns.[25]

[24]Although not the main focus of our paper, the risk-free in the economy (not shown) is also slightly affected by the introduction of the new asset. In particular, because of the reduction in the precautionary-savings demand in the case of a known dividend-growth rate, the price of the bond drops; that is, the risk-free rate increases (by about 0.05%). The effect in the case of learning is even smaller.

[25]With heterogeneous beliefs, the asset's expected return is lower than that in the pre-innovation period after about eighty periods (twenty years), which has a positive impact on the date-τ price-dividend ratio.

Figure 6: Asset Prices
This figure shows the dynamics of the prices of the financial assets over time, based on the parameter values described in Section 3.1. Panels A and B show the average price-dividend ratio for the new asset and the traditional asset, respectively.



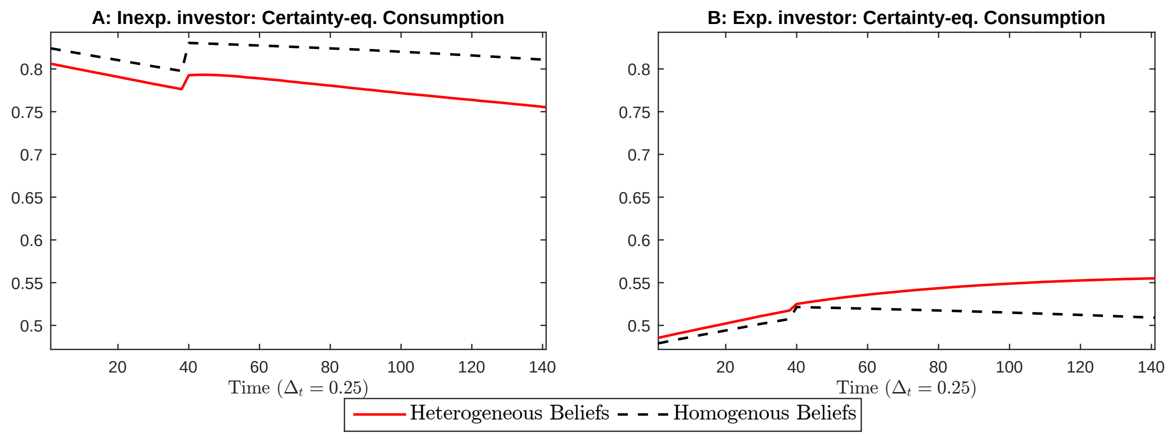
The effect of the introduction of the new asset on the price-dividend ratio of the traditional asset is substantially smaller in relative terms (Panel B of Figure 6). In particular, if investors have homogeneous beliefs, then the increase in the interest rate (due to the absence of a precautionary savings motive) leads to an increase of the asset's expected return and, thus, a small drop in the price-dividend ratio (dashed line in Panel B). In contrast, if investors have heterogeneous beliefs, the price-dividend ratio is basically unaffected because the effects on the interest rate and the asset's risk premium offset each other (solid line in Panel B).

3.7 Welfare

Finally, we briefly discuss the implications of financial innovation for investors' welfare, measured by investors' certainty-equivalent consumption (normalized by total output), and computed under the investors' subjective beliefs. Note that in our model, the beliefs of experienced investors coincide with the objective beliefs. Also, while inexperienced investors do not know the true growth rate of dividends for the new asset, their beliefs are unbiased and their learning is fully rational (Bayesian). So, in this sense, neither group of investors has distorted beliefs, and hence, it is reasonable to compute welfare using the

Figure 7: Welfare

This figure shows the dynamics over time of the investors' certainty-equivalent consumption, normalized by total output. Panels A and B show the average certainty-equivalent consumption for the inexperienced and the experienced investor, respectively. The figure is based on the parameter values described in Section 3.1.



beliefs of each group of investors.[26] However, we still caution the reader about drawing strong inferences regarding the welfare implications of financial innovation because there are many aspects of the real world that are missing from our stylized model.

Recall that inexperienced investors are endowed with a majority of the wealth. Thus, their level of certainty-equivalent consumption (Panel A of Figure 7) is higher in general than that of experienced investors (Panel B). In the pre-innovation period ($t < 40$), the certainty-equivalent consumption of the inexperienced investors is declining over time (Panel A), whereas it is increasing for the experienced investors (Panel B). This is because of the better investment opportunities available to experienced investors, which lead to higher portfolio returns, and in turn, higher consumption growth.

The introduction of the new asset at $\tau = 40$ is beneficial for both groups of investors, and it leads to a jump in welfare levels. Inexperienced investors see their welfare increase

[26] We computed welfare also under objective beliefs for both investors. For experienced investors this has no impact because their beliefs coincide with the objective measure, so Panel B of Figure 7 is unchanged. But, also for inexperienced investors (Panel A) the pattern is very much the same, with the introduction of the new asset at $\tau = 40$ leading to an improvement in welfare. This is because at introduction, inexperienced investors actually have the right beliefs (that is, their prior is unbiased). Later on, their beliefs will differ from true ones, but on average their beliefs remain unbiased. For a more detailed discussion of computing welfare under distorted beliefs, see Brunnermeier, Simsek, and Xiong (2014).

with financial innovation because having access to a new asset improves their investment opportunity set, which allows them to achieve higher expected long-term portfolio returns, and consequently, higher expected consumption growth. This effect is stronger in the case of homogeneous beliefs because then inexperienced investors know the true dividend-growth rate for the new asset, and hence, are willing to allocate substantial wealth to the new asset more quickly.

Experienced investors also benefit from financial innovation because it allows them to achieve better risk sharing; that is, they can share the risk of holding the new asset. Again, the welfare gains at introduction ($\tau = 40$) are stronger in the case of homogeneous beliefs because the improvements in risk sharing take place faster. However, in the long-run, experienced investors are better off in the case of heterogeneous beliefs because then they have an information advantage relative to inexperienced investors.

4 Extensions and Alternative Specifications

To study the robustness of our results, we now evaluate the impact of financial innovation for several variations of the baseline economy. For each of these variations, we reproduce all our results, but to save on space, we report only our main object of interest, the moments of asset returns for the new asset.

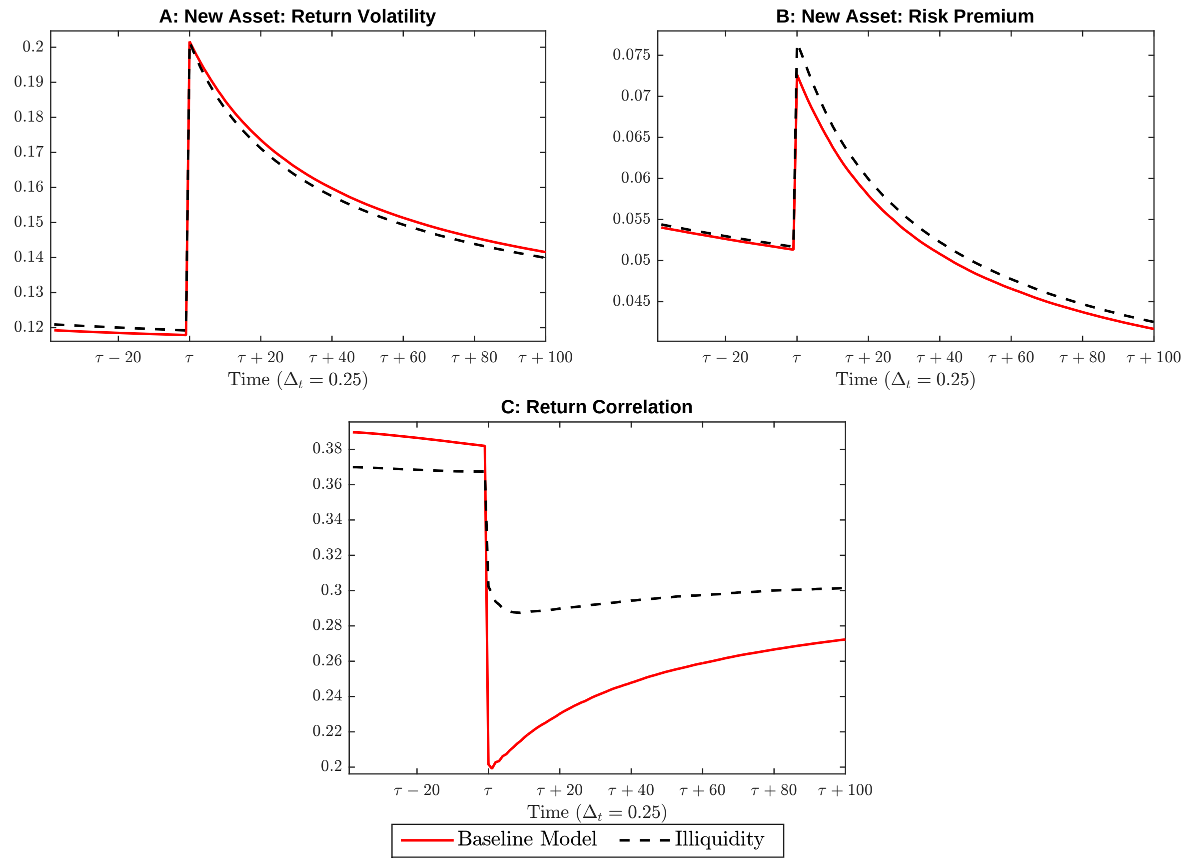
4.1 Extension: Illiquidity

First, we consider an economy in which the new asset is illiquid after being introduced. In practice, trading in new asset classes often entails sizeable trading costs, which we model as a proportional transaction cost; that is, each investor has to pay a constant fraction $\kappa = 2.5\%$ of the (dollar) value of the trade.[27] Qualitatively, our main insights

[27]Rather than assuming that the transaction cost is a deadweight loss to society, we assume that it is added back to the consumption of investors *after* they have made their consumption and portfolio decisions, thereby eliminating any wealth effects; the transaction cost paid by the group of investors buying shares is equal to that paid by the group selling shares, so the total transaction cost is redistributed equally between the two groups. However, if one were to assume that the transaction cost is a deadweight cost, it would not affect any of our results because investors optimize their trading decisions, and therefore, the transaction costs incurred in equilibrium are small. Details of how the model with

Figure 8: Extension: Illiquidity

This figure shows the dynamics of the new asset's return moments over time. The figure is based on the extension of the basic model to allow for transaction costs, as described in Section 4.1. Panels A to C show the average conditional return volatility, the average conditional risk premium and the average conditional return correlation between the traditional asset and the new asset, respectively. The results are plotted in event time, with time τ marking the date of financial innovation.



are not affected by illiquidity, and, as we see from Panels A and B of Figure 8, even quantitatively the effect of transaction costs is small.

The main effect of transaction costs is on the trading decisions of investors. In the presence of transaction costs, inexperienced investors rebalance their holdings in the new asset less aggressively following updates in their beliefs, which slightly limits the increase in the new asset's return volatility (Panel A). Moreover, instead of trading the new asset

transaction costs is solved (by extending the dual formulation of Buss and Dumas (2016)) are given in the Internet Appendix.

at a cost, inexperienced investors often use the correlated traditional asset as a substitute. Consequently, shocks to the cash flows of the new asset spill over to the traditional asset, substantially *increasing* the return correlation between the new and traditional risky assets in the post-innovation period relative to the base case with zero transaction costs; thus, decreasing the diversification benefits from the new asset (compare the solid line to the dashed line in Panel C of Figure 8).[28] Transaction costs also give rise to a *liquidity premium*, which increases the total risk premium of the new asset (Panel B).

4.2 Extension: Financial Innovation

In practice, financial intermediaries may make a new asset class available only if there is sufficient demand for it. To model this, we consider two extensions to the baseline model in which the decisions to introduce the new asset are endogenous.

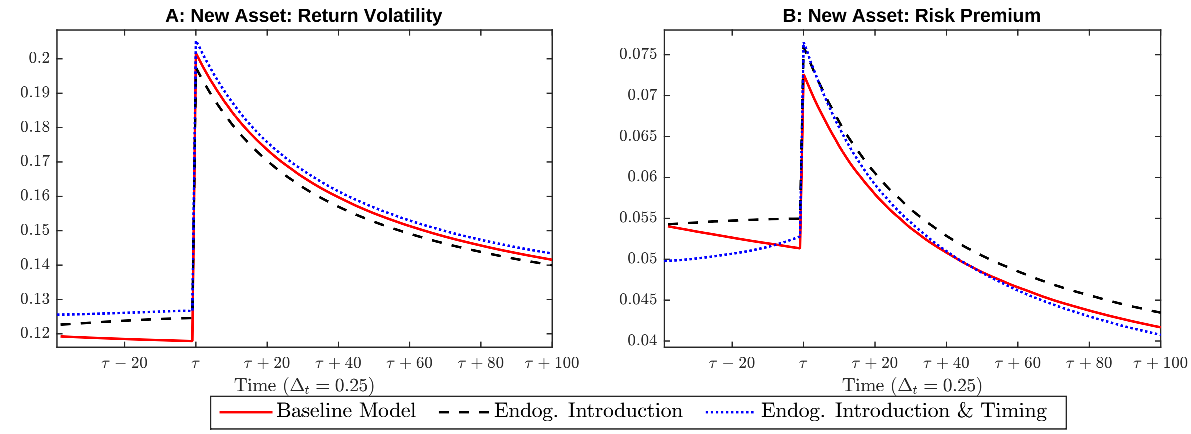
In the first extension, we assume that at time $\tau = 40$, the new asset is introduced only if its share of aggregate dividends is higher than a threshold value, which we set to 20%.[29] Again, we see from Figure 9 that qualitatively, our predictions for the impact of financial innovation remain unchanged. Even quantitatively, the predictions for the new asset's return volatility and its risk premium after introduction are basically unaffected.

In the second extension, we study the case in which both the introduction *and* the timing of financial innovation are endogenous. Note that so far we had assumed that if the new asset was not introduced at time τ, it would never be introduced. In this extension, we assume that the new asset can be introduced at any date, if its share

[28]The economic mechanism that drives the correlation between the returns of the two assets is the following: Before the new asset is introduced, the correlation between returns of the traditional and new asset is high because positive cash-flow news for the new asset implies a wealth transfer in favor of experienced investors who hold all of this asset. For diversification reasons, this wealth transfer leads to disproportionately strong demand for the traditional asset, increasing its price, and hence, higher correlation. Once the new asset becomes available to inexperienced investors, who have to learn about its expected dividend-growth rate, the correlation drops for two reasons. First, now investors' portfolios are less concentrated, which reduces the wealth transfer and its positive effect on correlation. Second, positive cash-flow news for the new asset, now also leads to an upward revision of the inexperienced investors' perceived dividend-growth rate for the new asset, shifting their demand toward the new asset and reducing the traditional asset's price-dividend ratio, thereby reducing the return correlation of the two assets. Both of these effects are weaker in the presence of transaction costs, so the correlation drops much less in the presence of transaction costs.

[29]The threshold is set so that the unconditional probability (at date $t = 0$) of the new asset being introduced at $\tau = 40$ is still about 50%.

Figure 9: Extension: Endogenous Financial Innovation
This figure shows the dynamics of the new asset's return moments over time. The figure is based on the extension of the basic model described in Section 4.2. Panels A and B show the average conditional return volatility and the average conditional risk premium, respectively. The results are plotted in event time, with time τ marking the (endogenous) date of financial innovation.



of total dividends is above a threshold of 22.5%.[30] As a result, the timing of financial innovation is now stochastic. Once again, we see from Figure 9 that, qualitatively, the predictions remain unchanged.

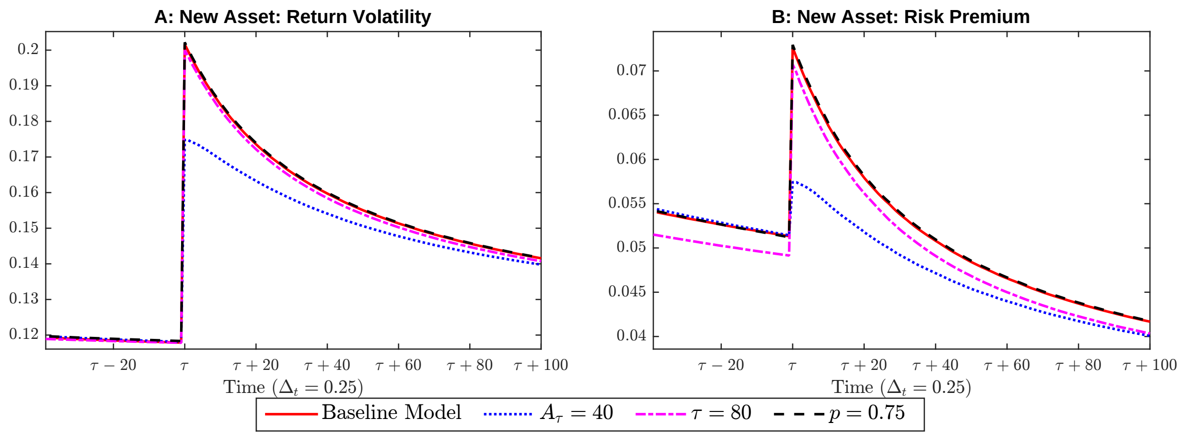
4.3 Alternative Specifications

Finally, we study the robustness of our results to our choices for various parameter values. Figure 10 highlights the implications of alternative choices for the beliefs of inexperienced investors. A more precise prior ($A_\tau = 40$ instead of $A_\tau = 20$ for the base case) implies that the inexperienced investors' demand for the new asset is less sensitive to cash-flow news due to smaller revisions in beliefs. Consequently, when the new asset becomes available, the increase in the new asset's return volatility and, in turn, its risk premium is smaller compared to the base case. Conversely, a less precise prior would strengthen the effects of financial innovation on the moments of asset returns. In

[30]This threshold is chosen so that the unconditional probability (at $t = 0$) of the new asset being available for trading for the inexperienced investors at time $\tau = 40$ (that is, the asset has been introduced at some point $t \leq \tau$) is about 50%.

Figure 10: Robustness: Alternative Specifications

This figure shows the dynamics of the new asset's return moments over time. Panels A and B show the average conditional return volatility and the average conditional risk premium, respectively. The figure is based on the alternative model specifications described in Section 4.3: a more precise prior ($A_\tau = 40$ instead of $A_\tau = 20$ for the base case), financial innovation occurring later (at $\tau = 80$ instead of $\tau = 40$ in the base case), and financial innovation that is more likely ($p = 0.75$ instead of $p = 0.50$ in the base case). The results are plotted in event time, with time τ marking the date of financial innovation.



contrast, if financial innovation occurs later (at $\tau = 80$ instead of $\tau = 40$ in the base case) or is more likely ($p = 0.75$ instead of $p = 0.50$ in the base case), the predictions remain—even quantitatively—unchanged.

Unreported results[31] show that widening the truncation bounds has no impact, which implies that our results are not driven by extreme beliefs. Moreover, reducing the dividend-growth volatilities to match aggregate consumption volatility or using a mean-reverting dividend share so that it has a stationary distribution, has qualitatively no effect. Similarly, changes in risk-aversion (γ), initial wealth shares ($w_{k,0}$), the initial dividend share ($\delta_{i,0}$), the horizon (T), and the frequency (Δ_t) lead to only small quantitative changes. Also, there are only small changes if one considers correlated dividends, in which case cash-flow news of the traditional asset affects revisions of the new asset's perceived dividend-growth rate.

[31] These results are reported and discussed briefly in the Internet Appendix.

5 Conclusion

In this paper, we study how asset prices are affected by *financial innovation.* The traditional view is that new asset classes, such as private equity, hedge funds, emerging market equity and debt, natural commodities, and real assets, should play a crucial role in the portfolios of all investors because of the substantial diversification benefits and potentially higher returns they offer. Moreover, the resulting consumption smoothing should lead to a decrease in the return volatility and risk premium of the new asset class.

Our main contribution is to show that when the new (inexperienced) investors are less well informed about the new asset class than the experienced investors who have been holding this asset, then many of these "intuitive" results are reversed. For instance, even after financial innovation occurs, there are *large differences* in the portfolios of experienced and inexperienced investors, resulting from the large negative intertemporal hedging demand of inexperienced investors because they are uncertain about the expected dividend-growth rate of the new asset and rationally learn about it over time. Financial innovation leads to an *increase* in the volatility of the portfolios of investors, and even after several decades have elapsed, inexperienced investors allocate only a small amount of their capital to the new asset class. Moreover, the learning of the inexperienced investors amplifies cash-flow fluctuations in the new asset, and thus, leads to a *higher* return volatility. The higher return volatility, together with a higher volatility of the SDF, contribute to an *increase* in the risk premium of the new asset upon its introduction.

Our analysis shows that it is important to account for differences in beliefs when making predictions about the effects of financial innovation. When investors differ in their beliefs, the results can be counterintuitive and very different from those in a setting with homogeneous beliefs, even if learning is fully rational.

A Optimality Conditions and Equilibrium

A.1 Investors' Optimality Conditions

The objective of each investor k is to maximize her expected lifetime utility given in equation (1), by choosing consumption, $C_{k,t}$, and the holdings in the available financial assets, $\theta_{n,k,t}, n \in \{0, \ldots, N_{k,t}\}$:[32]

$$V_{k,t}\big(\{\theta_{k,n,t-1}\}\big) = \max_{C_{k,t},\{\theta_{k,n,t}\}} \left[(1-\beta)\, C_{k,t}^{1-\frac{1}{\psi}} + \beta E_t^k \left[V_{k,t+1}\big(\{\theta_{k,n,t}\}\big)^{1-\gamma} \right]^{\frac{1}{\phi}} \right]^{\frac{\phi}{1-\gamma}},$$

subject to the budget equation (5).

Denoting the Lagrange multiplier associated with the budget equation by $\eta_{k,t}$, the Lagrangian can be written as

$$\mathcal{L}_{k,t} = \sup_{C_{k,t},\{\theta_{k,n,t}\}} \inf_{\eta_{k,t}} \left[(1-\beta)\, C_{k,t}^{1-\frac{1}{\psi}} + \beta E_t^k \left[V_{k,t+1}^{1-\gamma} \right]^{\frac{1}{\phi}} \right]^{\frac{\phi}{1-\gamma}}$$
$$+ \eta_{k,t} \big(\theta_{k,0,t-1} + \sum_{n=1}^{N_{k,t}} \theta_{k,n,t-1}\, D_{n,t} - C_{k,t} - \theta_{k,0,t}\, S_{0,t} - \sum_{n=1}^{N_{k,t}} \Delta\theta_{k,n,t}\, S_{n,t} \big),$$

and the corresponding first-order conditions are given by

$$\frac{\partial \mathcal{L}_{k,t}}{\partial C_{k,t}} = \frac{1}{1-\frac{1}{\psi}} \left\{ (1-\beta)\, C_{k,t}^{1-\frac{1}{\psi}} + \beta E_t^k \left[V_{k,t+1}^{1-\gamma} \right]^{\frac{1-\frac{1}{\psi}}{1-\gamma}} \right\}^{\frac{1}{1-\frac{1}{\psi}}-1} (1-\beta) \left(1 - \frac{1}{\psi}\right) C_{k,t}^{-\frac{1}{\psi}} - \eta_{k,t}$$
$$= (1-\beta)\, C_{k,t}^{-\frac{1}{\psi}}\, V_{k,t}^{\frac{1}{\psi}} - \eta_{k,t} \equiv 0, \tag{A1}$$

$$\frac{\partial \mathcal{L}_{k,t}}{\partial \eta_{k,t}} = \theta_{k,0,t-1} + \sum_{n=1}^{N_{k,t}} \theta_{k,n,t-1}\, D_{n,t} - C_{k,t} - \theta_{k,0,t}\, S_{0,t} - \sum_{n=1}^{N_{k,t}} \Delta\theta_{k,n,t}\, S_{n,t} \equiv 0, \quad \text{and} \tag{A2}$$

$$\frac{\partial \mathcal{L}_{k,t}}{\partial \theta_{k,n,t}} = \frac{1}{1-\frac{1}{\psi}}\, V_{k,t}^{\frac{1}{\psi}}\, \beta\, \frac{1-\frac{1}{\psi}}{1-\gamma}\, E_t^k \left[V_{k,t+1}^{1-\gamma} \right]^{\frac{\gamma-\frac{1}{\psi}}{1-\gamma}} (1-\gamma)\; E_t^k \left[V_{k,t+1}^{-\gamma} \frac{\partial V_{k,t+1}}{\partial \theta_{k,n,t}} \right] - \eta_{k,t} S_{n,t}$$
$$= \beta\, V_{k,t}^{\frac{1}{\psi}}\, E_t^k \left[V_{k,t+1}^{1-\gamma} \right]^{\frac{1-\frac{1}{\psi}}{1-\gamma}-1}\; E_t^k \left[V_{k,t+1}^{-\gamma} \frac{\partial V_{k,t+1}}{\partial \theta_{k,n,t}} \right] - \eta_{k,t}\, S_{n,t} \equiv 0. \tag{A3}$$

[32]For ease of exposition, in the following derivations we do not explicitly write the dependence of $V_{k,t}$ on the incoming (i.e., date $t-1$) asset holdings, $\{\theta_{k,n,t-1}\}$.

Using the Envelope Theorem we can compute the derivatives of the value function $V_{k,t}$ with respect to $\theta_{k,n,t-1}$:

$$\frac{\partial V_{k,t}}{\partial \theta_{k,0,t-1}} = \frac{\partial \mathcal{L}_{k,t}}{\partial \theta_{k,0,t-1}} = \eta_{k,t}, \tag{A4}$$

$$\frac{\partial V_{k,t}}{\partial \theta_{k,n,t-1}} = \frac{\partial \mathcal{L}_{k,t}}{\partial \theta_{k,n,t-1}} = \eta_{k,t}\,(D_{n,t} + S_{n,t}), \quad n \in \{1,2\}. \tag{A5}$$

In summary, the optimality conditions for each investor k are given by the following set of equations. First, the budget equation arising from (A2):

$$C_{k,t} + \theta_{k,0,t}\,S_{0,t} + \sum_{n=1}^{N_{k,t}} \Delta\theta_{k,n,t}\,S_{n,t} \;=\; \theta_{k,0,t-1} + \sum_{n=1}^{N_{k,t}} \theta_{k,n,t-1}\,D_{n,t}, \tag{A6}$$

which equates the uses and sources of funds. Second, the pricing equations, arising from equations (A3) to (A5), which equate the price of an asset to the expected payoff from holding it:

$$S_{0,t} = E_t^k\left[M_{k,t+1}\right],$$

$$S_{n,t} = E_t^k\left[M_{k,t+1}\left(S_{n,t+1} + D_{n,t+1}\right)\right], \quad n \in \{1,2\},$$

where the stochastic discount factor $M_{k,t+1}$, given in (6), subsumes the Lagrange multiplier $\eta_{k,t}$ from equation (A1).

A.2 Characterization of Equilibrium

Equilibrium in the economy can then be characterized by the following set of equations: the budget equation (A6), the "kernel conditions" that equate the prices of the assets across investors:

$$E_t^1\left[M_{1,t+1}\right] = E_t^2\left[M_{2,t+1}\right], \tag{A7}$$

$$E_t^1\left[M_{1,t+1}\left(S_{n,t+1} + D_{n,t+1}\right)\right] = E_t^2\left[M_{2,t+1}\left(S_{n,t+1} + D_{n,t+1}\right)\right]; \quad n \in \{1,2\}, \tag{A8}$$

and the market-clearing conditions:[33]

$$\sum_{k=1}^{2} \theta_{k,0,t} = 0, \quad \text{and} \quad \sum_{k=1}^{2} \theta_{k,n,t} = 1, \quad n \in \{1,2\}. \tag{A9}$$

[33] By Walras' law, market clearing in the asset markets guarantees market clearing for the consumption good.

B Numerical Algorithm

We use the time-shift proposed by Dumas and Lyasoff (2012) to obtain a recursive system. At date t, the "shifted" system of equations consists of the date-t kernel conditions (A7) and (A8), the date-t market-clearing conditions (A9), and the date-$t+1$ budget equations (A6):

$$C_{k,t+1,j} + \theta_{k,0,t+1,j} S_{0,t+1,j} + \sum_{n=1}^{N_{k,t}} \left(\theta_{k,1,t+1,j} - \theta_{k,1,t}\right) S_{1,t+1,j} \leq \theta_{k,0,t} + \sum_{n=1}^{N_{k,t}} \theta_{k,n,t}\, D_{n,t+1,j}, \forall k, j,$$

where the J future states (nodes) are denoted by $j = 1, \ldots, J$.[34] In total, we have a system of $2K + 2\,N_{k,t}$ equations with $2K + 2\,N_{k,t}$ unknowns: next period's consumption, $C_{k,t+1,j}$, for both investors and J states, and both investors' holdings in the assets, $\theta_{k,n,t}$.

The system of equations is solved recursively, starting from $T-1$. At each date t, we solve the equation system over the *grid of the state variables*. Next, when solving the system for date $t-1$, we interpolate (over the grid) the optimal date-t portfolio positions, $\theta_{k,n,t}$ and corresponding security prices, $S_{n,t}$, using the terminal conditions $\theta_{k,n,T} = 0$ and $S_{n,T} = 0$, $\forall n, k$. After solving the shifted system for all dates $t \in \{0, ..., T-1\}$, one has solved all equations from the global system—except the date-0 budget equations, which have not been used because of the time shift. Thus, one only needs to solve the time-0 budget equations based on interpolating functions for the date-0 prices, $S_{n,0}$, and holdings, $\theta_{k,n,0}$. The endowed holdings $\theta_{k,n,-1}$ are exogenous to the system and reflect the incoming (endowed) wealth of the investors.

There are four state variables: (i) the dividend share of the first risky security $\delta_{1,t} \in (0,1)$, the dynamics of which follow from the joint dividend dynamics in (2); (ii) the expected dividend-growth rate of the new asset class as perceived by the inexperienced investors, $\mu_{2,t}$, with the dynamics specified in (3); (iii) the (deterministic) posterior variance of the inexperienced investors' beliefs, $A_t\,\sigma_2^2$, with the dynamics specified in (4); and (iv) the consumption share of the experienced investors, $\omega_{1,t} \in (0,1)$.

[34] We approximate the joint dynamics of the dividends in (2) using a four-node, equal probabilities tree with growth realizations $\{(u_1, u_2), (d_1, u_2), (u_1, d_2), (d_1, d_2)\}$, where $u_n \equiv \mu_n + \sigma_n$ and $d_n \equiv \mu_n - \sigma_n$ are chosen to match the expected dividend-growth rate and volatility of asset n. Under the inexperienced investors' probability measure, the probabilities are set to $p_{2,t}/2$ $(\left(1 - p_{2,t}\right)/2)$ for the first (last) two nodes, with $p_{2,t}$ chosen to match the inexperienced investors' perceived dividend-growth rate, $\mu_{2,t}$.

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