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Equity Premium and Monetary Policy in a Model with Limited Asset Market Participation

(Részvénykockázati prémium és monetáris politika megtakarító és megtakarításokkal nem rendelkező háztartások esetén)

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Contents

Abstract

We develop a dynamic stochastic general equilibrium model calibrated to US data to examine how monetary policy shocks affect income inequality and the equity premium. The model features Ricardian and non-Ricardian households and shows that a monetary policy tightening causes an endogenous redistribution of income from non-Ricardians to Ricardians. Ricardians' consumption comoves more strongly with asset returns, giving rise to high equity premia. We extend our model with several frictions and estimate it with generalized method of moments using US macroeconomic and financial data from 1960-2007. We find that the estimated model jointly matches the bond and equity premia. We complement our theoretical model with vector autoregression estimations and show that a tightening of US monetary policy increases equity premia.

JEL: E32, E44, G12.

Keywords: Limited Asset Market Participation, Monetary Policy, DSGE, Equity Premium.

Összefoglaló

A tanulmány első részében egy USA adatokra kalibrált általános egyensúlyi modellben megmutatjuk, hogy a monetáris politikának milyen hatása van a jövedelem egyenlőtlenségre és a részvénykockázati prémiumra. A model tartalmaz megtakarító (rikardói) és megtakarítani nem tudó háztartásokat. Megmutatjuk, hogy egy monetáris szigorítás (nem-várt kamatemelés) jövedelmet csoportosít át: a nem-rikardói háztartások bér-jövedelme (az egyetlen jövedelemforrásuk) csökken, míg a rikardói háztartások profit (osztalék)-jövedeleme növekszik. Emiatt a rikardói háztartások fogyasztása erősebben együttmozog a részvényhozammal, melynek része az osztalék. A tanulmány második részében az alapmodellt számos frikcióval kiegészítjük és megbecsüljük általánosított momentumok módszerével USA adatokon (1960-2007). A kibővített modellünk a kötvény- és részvénykockázati prémiumot együttesen magyarázza. Továbbá megmutatjuk egy vektor-autoregresszív modellben, ahol a monetáris politikai sokkokat rekurzív-módon identifikáltuk, hogy egy nem-várt monetáris szigorítást követően növekszik a részvény kockázati prémium.

1 Introduction

Following the recent financial crisis, there is a renewed interest in exploring the interactions between monetary policy and income inequality (Coibion et al., 2017, Davtyan, 2017). Traditionally, it has been assumed that the distributional effects of the monetary policy rate net out over the business cycle, and therefore, the interactions between monetary policy and inequality have rarely been examined.

However, some recent papers show that monetary policy affects income inequality (Coibion et al., 2017) through various channels, such as financial segmentation. It has also been shown that income inequality can become a monetary policy transmission channel itself through earnings heterogeneity (Auclert, 2019). This is because low-income households typically have a higher marginal propensity to consume, and therefore, these households may benefit from monetary expansion more than rich households do.

Although the literature examining the effects of monetary policy on income inequality is growing, the implications of income redistribution from a macro-finance perspective have not received sufficient attention in the literature so far. We try to bridge this gap in this paper. Specifically, our paper measures the effect of income redistribution on matching financial and macroeconomic moments jointly in a model with limited asset market participation (LAMP). Importantly, in our paper, income redistribution occurs endogenously, i.e., it is caused by monetary policy shocks. This approach extends the previous literature, which assumes exogenous redistribution shocks (see, e.g., Lansing (2015)). The current literature examining the effects of monetary policy on equity premia has focused on other issues, for example, on the role of market volatility (Mallick et al., 2017).

Our first contribution is to show that monetary policy shocks are the source of the high equity risk premia in a simple model with LAMP. Our model is populated by Ricardian and non-Ricardian households. The former have access to bonds to smooth their consumption ('optimizers'), while the latter do not. This unequal access implies that a limited share of the population participates in financial markets. Non-Ricardians receive only labor income, while Ricardians hold equity shares in firms. Ricardians are the sole recipients of dividend income, which we show is a key channel of income redistribution in the case of monetary policy shocks. When the share of non-Ricardians is sufficiently high, redistribution of income from non-Ricardians to Ricardians is significant, and the comovement between Ricardians' consumption and the return on equity is high, giving rise to a large equity risk premium. The equity risk premium is defined as the covariance between Ricardians' consumption and the return on the equity.

To illustrate how redistribution occurs in our baseline model, we consider a contractionary monetary policy shock that elevates nominal and real interest rates through the Taylor rule. Higher rates lead Ricardians to delay their consumption expenditures. Lower consumption demand is associated with a decrease in labor demand and production by firms with rigid prices, as they cannot respond to a decrease in demand by reducing prices.[1] A decline in wages puts downward pressure on non-Ricardians' consumption but creates higher profits (dividends) and yields on the assets held by Ricardians. Hence, there is a redistribution of income from non-Ricardians to Ricardians. The higher the share of non-Ricardians, the stronger is the dividend channel and therefore the comovement between Ricardian consumption and asset returns. As a result, this comovement gives rise to sizable equity premia and a high standard deviation of the return on equity.

Our paper is the first to derive a closed-form solution for equity premia on the basis of monetary policy shocks in a model with LAMP.[2] The closed-form solution helps decompose the equity premium into two main components: the price of risk and the quantity of risk. We show that it is the price of risk (a model-specific component) that is driving the equity premium and not the quantity of risk (the variance of the monetary policy shock). Moreover, our closed-form solution makes it possible to determine how the model's deep parameters affect the price of risk. We also provide empirical evidence for this channel in the form of a simple vector autoregression (VAR) model where monetary policy shocks are identified recursively.

[1] In our model, price rigidity is necessary for monetary policy shocks to drive the equity premium.

[2] We use the loglinear asset-pricing framework of Campbell and Shiller (1988) to provide a closed-form solution for the level of the equity premium.

The model we use has two additional desirable properties. First, the equity premium is high, with a risk-aversion coefficient equal to one.[3] Second, the persistence of the monetary policy shock is not counterfactually high, which allows us to arrive at a large equity premium. This is in contrast with de Paoli et al. (2010) and Wei (2009), who use a rigid price model with a representative household and real frictions (habits in consumption and capital adjustment costs). In our paper, the persistence of the monetary policy shock is in line with empirical estimates of approximately 0.8 (see Carrillo et al. (2007) and Rudebusch (2006)). Even with a persistence of zero (which is widely assumed in the earlier monetary business cycle literature), the equity premium in our model is higher than that in the representative agent model.

Our second contribution is the estimation of an extended version of our baseline model by the generalized method of moments (GMM) on US macroeconomic and financial data for the period 1960-2007. In particular, we use the GMM to match the mean, variability and first- and fifth-order autocorrelations of seven time series. Our extended model contains various additional frictions, such as habits in consumption, Epstein-Zin preferences and more realistic fiscal setups. This extension helps capture the bond and equity premium puzzles jointly. Beyond matching the equity premium and a set of macroeconomic moments, this setup allows the model to match the bond premium. Within the extended model, we consider two types of fiscal setups: one where the debt is constant (a simplified fiscal setup) and another with time-varying debt (an empirically more realistic setup). In both fiscal setups, the debt is retired by taxes on labor.

In line with previous literature, we find that in the extended setup, technology shocks are also necessary for the high equity premium. Since Jermann (1998) we know that consumption habits induce excess volatility of the risk-free rate due to the aversion of Ricardian households to short-run fluctuations in the consumption stream (the so-called risk-free rate puzzle). LAMP helps resolve the risk-free rate puzzle, as it generates a higher precautionary savings effect. This effect reduces the level as well as the volatility of the risk-free rate so that the equity premium is easier to match.

The recent literature tries to jointly match the equity and bond premium puzzles (see, e.g., Menna and Tirelli (2014)). To do so in this case, our extended model also features Epstein-Zin preferences that facilitate matching of the bond premium in the yield of long-term nominal government bonds. Epstein-Zin preferences make Ricardian households concerned about not only short- but also long-run risks, and hence, the risk premium in long-maturity bonds can be easily matched. In the model, the bond-risk premium is mainly a compensation for inflation risks due to technology shocks that engineer positive comovement between consumption and real bond yields, making long-term bonds a poor hedge.

The idea that limited participation can help explain equity premia is not new. In a chapter of the Handbook of the Equity Risk Premium, Donaldson and Mehra (2008) provide a complete section on models with market incompleteness. We make two important departures from earlier models in the literature. First, as we explained above, the equity premium in our model is driven by monetary policy shocks and not technology shocks. Second, the earlier models described in Donaldson and Mehra (2008) are endowment economies in which the consumption and dividend streams are exogenously given, and the economies feature a fixed labor supply.[4] In our paper, we depart from the unrealistic assumptions of the endowment economy and fixed labor supply. Instead, we consider a production economy and variable labor supply, which make it more challenging to match the equity premium. With a variable labor supply, agents can easily insure themselves against negative shocks by working more to avoid a decrease in consumption. Our model considers a production economy with a variable labor supply, which acts as insurance against bad shocks. As a result, fluctuations in consumption are less influenced by dividends and asset returns.[5]

We do not claim that monetary policy shocks are the most important for business cycles. To account for business cycles, we need several additional highly persistent shocks (e.g., technology shocks as well as price and wage markup shocks), as is commonly seen in the monetary business cycle literature (see, e.g., Smets and Wouters (2007)). In our baseline model, we only focus on monetary policy shocks to clearly illustrate the mechanism that helps generate a high and volatile equity premium. The

[3] See Cochrane (2000), who explains that the equity premium can be raised easily with higher risk aversion at the cost of higher volatility of the risk-free rate.

[4] There are some exceptions, however, such as Danthine et al. (2008), who consider a production economy. It may be reasonable to assume that the labor supply is fixed. This is so if we consider the micro evidence on the labor supply elasticity (close to zero) for working-age males, which facilitates high equity premia (Lansing, 2015).

[5] Note that our paper considers a model with a production economy and predicts that the equity premium increases with the degree of limited asset market participation. This is in contrast to papers that consider endowment economies (see Polkovnichenko (2004) and Walentin (2010)) and predict exactly the opposite. In our paper, labor income is endogenous and is influenced by monetary policy. In endowment economies, income is simply the realization of a stochastic shock.

autocorrelation of our monetary policy shock is in line with the estimates of Carrillo et al. (2007) and Rudebusch (2006). As we show, the autocorrelation is important for reconciling the high equity premia (in line with the findings of Wei (2009)).

Lansing (2015) shows that exogenous income redistribution shocks are among the key drivers of high premia on unlevered equity. He uses a model with heterogeneous agents (stockholders and nonstockholders) and a fixed labor supply. Our model is different from Lansing's in at least four important dimensions: i) we employ a two-agent New Keynesian (TANK) model and not an RBC-type concentrated ownership model; ii) the redistribution of income in our model happens endogenously due to the TANK structure and not because of redistribution shocks; iii) monetary policy shocks (and not 'redistribution shocks') cause redistribution from non-Ricardian to Ricardian households; and finally, iv) our model features an elastic labor supply, in contrast to Lansing's (2015) model, where the labor is fixed.

Our paper is also related to Motta and Tirelli (2014), who examine the redistributive effects of monetary policy shocks in a model with Ricardians and non-Ricardians. However, their paper does not examine the model's asset-pricing implications. Our paper aligns with Menna and Tirelli (2014), who employ a limited asset market participation framework similar to our framework. However, they focus on the different frictions, such as consumption habits, capital adjustment costs and wage rigidities, to explain the equity premium. In their model, the equity premium is driven by permanent technology shocks, whereas in this paper, it is a compensation for monetary policy shocks.

Finally, we note that the model used in this paper is a simplified version of the newly popular HANK (heterogeneous agent New Keynesian) models (see Kaplan et al. (2018)). Indeed, Bilbiie (2020) and Debortoli and Gali (2017) argue that our simplified two-agent New Keynesian (TANK) model captures most features of the computationally intensive HANK models sufficiently well.

The remainder of the paper is organized as follows. Section 2 offers empirical evidence in support of rising equity premiums in response to contractionary monetary policy shocks. Section 3 describes the model and the derivation of the equity premium formula. Section 4 presents the parameterization of our model. Section 5 describes the performance of our model relative to the representative agent model. Section 6 describes the robustness checks. Sections 7 and 8 provide the GMM estimation of our extended model. Finally, we conclude. An online appendix with model derivations and additional results follows.

2 Empirical evidence

In this section, we provide empirical evidence to motivate our theoretical model. In particular, we are interested in how the equity premium responds to a monetary contraction (i.e., an increase in the short-term interest rate) using actual data. We estimate a VAR model with quarterly US data on five variables (unemployment, growth rate of money supply, inflation rate, equity premium, and short-term nominal interest rate) plus a constant for 1960Q1-2007Q1.[6] We use one lag (based on the Hannan-Quinn information criterion) in the estimation.

The monetary policy shock is identified in a standard recursive way. The variables are ordered, as stated above, beginning with the unemployment rate and ending with the interest rate.[7] Intuitively, our recursive identification scheme implies that the error terms in each regression (for each row of the matrix) are uncorrelated with the error term in the preceding equations. For the first row, unemployment is the dependent variable, and the regressors are the lagged values of each variable. For the second row, money is the dependent variable, and the regressors are the contemporaneous values of unemployment plus the lag of each endogenous variable, etc. Stock and Watson (2001) argue that the estimation of each equation by ordinary least squares produces residuals that are uncorrelated across equations.

Figure 1 presents the impulse response of each variable in the VAR to a contractionary monetary policy shock (an increase in the nominal interest rate). We make the following observations. First, the equity premium increases following a monetary tightening. The maximum effect occurs approximately one to two quarters after the shock. Second, unemployment increases after a monetary contraction, with the strongest effect materializing after approximately two years. This result is in line with the typical findings regarding the speed of monetary policy transmission to economic activity. Third, we find that money growth is negatively associated with interest rates and bottoms out in less than eight quarters. Fourth, we fail to find that inflation responds significantly to monetary shocks. Further, we find that the rise in the equity premium in response to more restrictive monetary policy is robust to the use of a shorter sample (1980Q1-2007Q1) and more lags (two) in the VAR as well as the inclusion of a linear trend in the regression (these results are available upon request).

[6] The unemployment rate, inflation rate and short-term nominal interest rate are the variables used by Stock and Watson (2001) to measure the effects of monetary policy shocks. In this paper, two more variables are added to the VAR: the equity premium and the growth rate of the money supply. The inflation rate is the annualized percent change in the CPI, i.e., $\pi = 400log(P_t/P_{t-1})$. The short-term nominal rate is the annualized value of the US federal funds rate, so it is multiplied by four hundred. The equity premium is based on the S&P 500 and obtained from the online stock price dataset of Shiller (2017). The money supply is the log of the growth rate of the money aggregate M2 multiplied by one hundred. The unemployment rate for individuals aged 15-64 years for all persons in the United States is multiplied by one hundred. For more details on the data, see the data description in the online appendix.

[7] Consider a structural vector autoregression (SVAR) of the form:

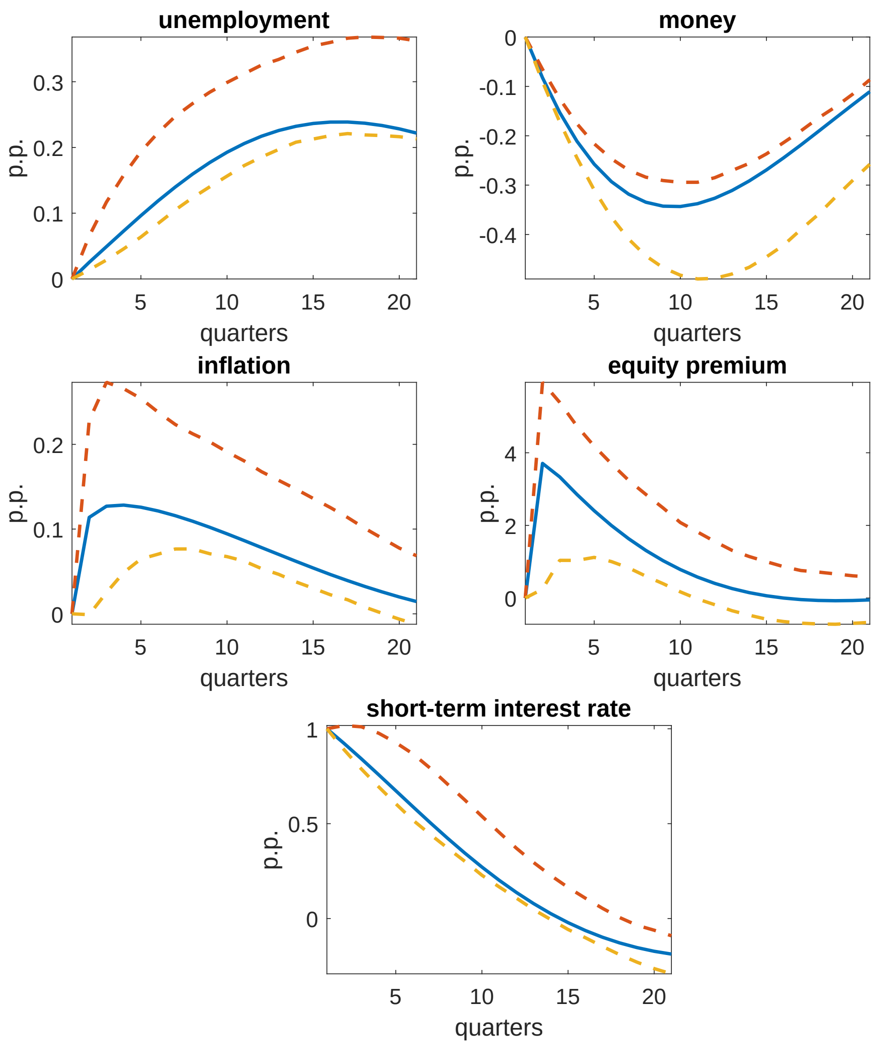
$$B_0 x_t = B_1 x_{t-1} + B_2 x_{t-2} + \dots + B_p x_{t-p} + \epsilon_t,$$

where x is a vector of variables, $B_0, B_1, \dots, B_p$ are matrices and the structural shocks are $\epsilon \sim i.i.dN(0, I)$. However, we can estimate the VAR in reduced form (multiplying both sides of the previous equation by B_0^{-1})

$$\begin{aligned} x_t &= B_0^{-1} B_1 x_{t-1} + B_0^{-1} B_2 x_{t-2} + \dots + B_0^{-1} B_p x_{t-p} + B_0^{-1} \epsilon_t, \\ &= A_1 x_{t-1} + A_2 x_{t-2} + \dots + A_p x_{t-p} + \nu_t, \end{aligned}$$

where $A_i = B_0^{-1} B_i$ and the variance-covariance matrix is given by $E_t(\nu_t \nu_t') = B_0^{-1} B_0^{-1'} = \Omega$.

Figure 1
The effects of a contractionary monetary policy shock in the US



Notes: Recursively identified VAR model (with a constant in the regressions), 1960:Q1-2007:Q1, 68th percentile bootstrapped confidence intervals (1000 replications) following Hall (1992). Time is in quarters. 1 p.p. shock in the interest rate. The interest rate, inflation rate and equity premium are all annualized.

3 Model

3.1 HOUSEHOLDS

A share of the households λ have no access to the financial market (see, e.g., Bilbiie (2008)). These households cannot smooth their consumption intertemporally through risk-free bonds and shares in equity. Therefore, their consumption completely depends on their disposable income in each period. These households are called non-Ricardians (r).

The remaining share of households $1-\lambda$ are Ricardians (optimizers, o) and engage in the intertemporal trade of assets to smooth fluctuations in income.

Each household, either Ricardian or non-Ricardian (denoted $i = o, r$), features a utility function that distinguishes between consumption (C_t^i) and leisure ($1-N_t^i$):

$$U = \frac{(C_t^i)^{1-\sigma}}{1-\sigma} - \frac{(N_t^i)^{1+\varphi}}{1+\varphi}. \tag{1}$$

σ is the inverse of the elasticity of intertemporal substitution, and φ is the inverse of the Frisch labor supply elasticity.

The consumption of the two types of households can be aggregated through

$$C_t = \lambda C_t^r + (1-\lambda)C_t^o.$$

The consumption index (C_t) is obtained via the standard Dixit-Stiglitz aggregator, which sums a continuum of goods on the unit interval $[0,1]$, with $\epsilon > 0$ as the elasticity of substitution among goods.

The intertemporal budget constraint of optimizers is given by

$$\begin{aligned} &P_t C_t^o + R_t^{-1}\{B_{t+1}^o\} + V_t^{eq} S_t^o \\ &= (V_t^{eq} + P_t D_t^o) S_{t-1}^o + W_t N_t^o + B_t^o - P_t T_t^o - P_t ST^o, \end{aligned} \tag{2}$$

where P_t is the price level, B^o denotes the amount of nominal riskless government bonds held by Ricardian households, R_t is the gross nominal interest rate on one-period bonds, and W_t is the nominal wage. S_t^o is the number of firm shares owned by optimizers. V_t^{eq} and $P_t D_t^o$ denote the nominal value of shares and dividends received by Ricardians, respectively. T_t^o represents lump-sum taxes paid by optimizers, and ST^o is a steady-state lump-sum tax used to equate the steady-state consumption of both types of households ($C = C^o = C^r$).[8] All profits are paid out in the form of dividends, which are received by the optimizer and given by

$$P_t D_t^o = \frac{P_t D_t}{1-\lambda} = \frac{P_t Y_t - W_t N_t}{1-\lambda},$$

where D_t is the aggregate level of real dividends and D_t^o represents real dividends received by Ricardian households.

Non-Ricardians also maximize their utility in equation (1) subject to the budget constraint:

$$P_t C_t^r = W_t N_t^r + P_t ST^r,$$

where ST^r is a transfer to rule-of-thumb households that helps to equalise steady-state consumption of the two types of households.

There is a competitive labor market, as in Bilbiie (2008). The Ricardian and non-Ricardian labor supplies are aggregated through the following equation:

$$N_t = \lambda N_t^r + (1-\lambda)N_t^o,$$

where N_t denotes the aggregate labor supply. We do not include government consumption and investment to keep the model simple.

[8] Note that this approach differs from Bilbiie (2008), who uses a fixed cost of production to eliminate steady-state dividends and equalize the steady-state consumption of the two types of households.

3.2 FIRMS

Output is produced using a one-to-one production function (abstracting from technology shocks):

$$Y_t(i) = N_t(i).$$

Intermediaries are subject to Calvo-style price-setting frictions.[9] The profit maximization problem of an intermediary firm i at time t, which will not be able to reset its price between time t and time $t+k$, can be formulated as

$$\max_{P_t^*} \sum_{k=0}^{\infty} \theta^k Q_{t,t+k} \left[P_t^*(i) Y_{t+k|t}(i) - W_{t+k} N_{t+k}(i) \right], \tag{3}$$

where P_t^* is the optimal reset price at time $-t$, θ is the probability of not resetting the price, and $Q_{t,t+k}$ is the stochastic discount factor, defined as

$$Q_{t,t+k} \equiv \beta^k \left(\frac{C^o_{t+k+1}}{C^o_{t+k}} \right)^{-\sigma} \frac{P_t}{P_{t+k}}.$$

The profit maximization problem of the intermediary is also subject to the demand schedule for an individual product i:

$$Y_{t+k|t}(i) = \left(\frac{P_t^*(i)}{P_{t+k}} \right)^{-\epsilon} Y_{t+k|t}.$$

3.3 MONETARY POLICY

Monetary policy is described by a simple Taylor rule of the following form:

$$R_t = \beta^{-1} \Pi_t^{\phi_\pi} exp(\xi_t).$$

$\Pi_t = P_t/P_{t-1}$ represents gross inflation, ϕ_π measures the strength of the reaction of monetary policy to inflation, β^{-1} is the gross interest rate in the steady state, exp is the exponential function and ξ_t is a monetary policy shock:

$$\xi_t = \rho_\xi \xi_{t-1} + \sigma_\xi \varepsilon_t^\xi,$$

where ρ_ξ represents the persistence of the process ξ and σ_ξ denotes the standard deviation of the i.i.d. shock ε_t^ξ, which has a zero mean.

3.4 SOLUTION OF THE MODEL

A summary of the linearized equilibrium conditions is available in online Appendix A. The linear solution for output and inflation, as a function of the monetary policy shock, is provided in Proposition 1. Proposition 2 explains the determinacy of the model. Propositions 3 and 4 describe the linear formulation for the price-dividend ratio and the equity premium, respectively.

Proposition 1. *In the absence of state variables, the model has a closed-form solution for output and inflation, which is a function of the monetary policy shock:*

$$y_t = A_y \xi_t, \quad \pi_t = A_\pi \xi_t,$$

where $y_t \equiv (Y_t - Y)/Y$ and $\pi_t \equiv (\Pi_t - \Pi)/\Pi$ denote linearized output and inflation, respectively; the absence of the time index indicates the steady state. The coefficients A_y and A_π are defined as

$$A_y \equiv -\frac{(1-\lambda)(1-\beta\rho_\xi)}{\Gamma(1-\beta\rho_\xi)\sigma - \Gamma\rho_\xi(1-\beta\rho_\xi)\sigma + (1-\lambda)(\phi_\pi - \rho_\xi)\kappa(\sigma+\varphi)},$$

$$A_\pi \equiv \frac{\kappa(\sigma+\varphi)A_y}{1-\beta\rho_\xi}, \Gamma \equiv 1 - \lambda\,(1+\varphi)\,, \kappa \equiv \frac{(1-\theta)(1-\beta\theta)}{\theta(1+\epsilon\varphi)}.$$

For the proof, see online Appendix A.

[9] As in Woodford (2003, chapter 3), we assume that there is strategic complementarity in price setting in the form of a specific labor market, which leads to a reduction in the slope of the New Keynesian Phillips Curve and thus causes shocks to have larger real effects (rather than changes in relative prices).

In line with conventional wisdom, a restrictive monetary shock ($\xi_t > 0$) decreases output and inflation, i.e., $A_y < 0$ and $A_\pi < 0$, provided that the share of non-Ricardians does not exceed a threshold value (see online Appendix A), and the Taylor principle is satisfied ($\phi_\pi > 1$).

3.5 DETERMINACY PROPERTIES OF THE MODEL

To study the determinacy properties of the model (the next proposition), we generate the IS curve. To do so, we first recall the linear bond Euler equation of the Ricardians

$$c_t^o - E_t c_{t+1}^o = -(dR_t - E_t \pi_{t+1}).$$

The previous equation and the connection between Ricardian consumption and aggregate output are combined as $c_t^o = A_c y_t$ (for the derivation of this equation, see online Appendix B):

$$y_t = E_t y_{t+1} - \Gamma^{IS}(dR_t - E_t \pi_{t+1}), \text{ where } \Gamma^{IS} \equiv \frac{1}{A_c} = \frac{1-\lambda}{1-\lambda(1+\varphi)}.$$

dR_t is defined as $R_t - R$, and we restrict the analysis to the case of $\varphi > 0$.[10]

Note that $\partial \Gamma^{IS}/\partial \lambda > 0$ as long as $(1-\lambda)/\lambda > \varphi$. Therefore, the IS equation above lends support to the claim (see the results section of this paper) that a larger share of non-Ricardians leads to more effective monetary policy due to the higher sensitivity of aggregate demand to the real interest rate, i.e., Γ^{IS} increases in λ.

Proposition 2. *When $\lambda \leq 0.39$ and/or the labor supply is sufficiently elastic (φ is low), the Taylor principle ($\phi_\pi > 1$) leads to determinacy of the model with baseline parametrization, and the slope of the IS curve Γ^{IS} is negative.*
When $\lambda > 0.39$, the slope of the IS curve is positive and passive monetary policy ($\phi_\pi < 1$) guarantees determinacy. For the proof, see Bilbiie (2008), who employs a similar model.

For the remainder of the paper, we abstract from cases wherein $\lambda > 0.39$, and this region can be described by the 'inverted aggregate demand logic' (IADL), where $\phi_\pi < 1$ yields determinacy (for further information, see Bilbiie (2008)).

3.6 PRICING THE MARKET PORTFOLIO

We use the loglinear asset pricing framework of Campbell and Shiller (1988) to price the market portfolio of equally weighted shares and to derive a closed-form solution for the equity premium. A similar strategy is also followed by Wei (2009).

Proposition 3. *The return on the market portfolio of equally weighted shares can be written as as*

$$rr_{t+1} = \kappa_0 + \kappa_1 z_{t+1} - z_t + \Delta d_{i,t+1}, \tag{4}$$

where z_t denotes the price-dividend ratio, Δd_{t+1} is the growth rate of real dividends, and κ_0 and κ_1 are constants. Campbell and Shiller (1988) show that $\kappa_1 \simeq 1$. z_t is a function of the state variable, which is the monetary policy shock ξ_t:

$$z_t = A_{z0} + A_{z1}\xi_t, \tag{5}$$

where A_{z0} is a constant that can be ignored and

$$A_{z1} \equiv \frac{A_c A_y (1-\rho_\xi)}{1-\beta\rho_\xi} - \frac{(1-\rho_\xi) A_y \kappa_{d\xi}}{1-\beta\rho_\xi},$$

[10] At this point, we make two observations. First, the slope of the IS curve is almost the same as that of Bilbiie (2008). The only difference comes from the fact that Bilbiie eliminates steady-state dividends through a fixed cost in production, which adds another multiplicative term to the slope in his paper. Second, we must abstract from the case of infinitely elastic labor supply ('indivisible labor'), $\varphi = 0$, because this makes the wealth heterogeneity across households irrelevant and the slope of the IS curve becomes independent of the share of the non-Ricardian households.

where

$$A_c \equiv \frac{1-\lambda(1+\varphi)}{1-\lambda}.$$

Real dividend growth is given by

$$\Delta d_{t+1} = \kappa_{d\xi} A_y \Delta\xi_{t+1}, \tag{6}$$

where $\kappa_{d\xi} \equiv 1 - \frac{W(1+\varphi)}{1-W}$ *and* $W = \frac{\epsilon-1}{\epsilon}$. *For the proof, see online Appendix B.*

Proposition 3 states that there is a linear relationship between the expected dividend growth and the difference between the expected and current monetary policy shocks.

Proposition 4. *The equity premium is calculated as* $-cov_t(sdf_{t,t+1}, rr_{i,t+1})$*, where* $sdf_{t,t+1} \equiv -A_c A_y(\xi_{t+1} - \xi_t)$ *is the linearized stochastic discount factor. The equity premium is given by* $ep_t = A_c A_y\{\kappa_1 A_{z1} + k_{d\xi} A_y\}\sigma^2_{\xi}$.

Proof. To derive a closed-form solution for the equity risk premium, we first decompose the covariance term into the price of risk and the amount of risk:

$$\begin{aligned} ep_t &= A_c A_y cov_t(\xi_{t+1}, rr_{t+1}) \\ &= A_c A_y(\kappa_1 A_{z1} + k_{d\xi} A_y) \times \sigma^2_{\xi}, \end{aligned}$$

where $A_c A_y(\kappa_1 A_{z1} + k_{d\xi} A_y)$ is the price of risk and σ^2_{ξ} is the quantity of risk. For the proof, see online Appendix B. □

3.7 DISCUSSION OF THE EQUITY PREMIUM FORMULA

In line with Hördahl et al. (2008) and Sangiorgi and Santoro (2005), we decompose the equity premium into two parts. The first part measures the market price of risk. The second part represents the amount of risk, which is the covariance between the return on the asset and the innovation of the shock. As Hördahl et al. (2008) argue, the market price of risk is of particular interest because it is independent of the special characteristics of the asset being priced (a premium for a given amount of risk). The second term measures the nondiversifiable riskiness of an asset.

Both the price and the amount of risk increase (in absolute value) with more limited asset market participation (higher λ). It is useful to observe the individual determinants of the price of risk. $\kappa_1 A_{z1}$ captures the negative effect ($A_{z1} < 0$) of the monetary policy shock on the price-dividend ratio (z_t). Dividends alone have a direct positive effect on the amount of risk ($k_{d\xi} A_y > 0$).

For our calibration, the negative sign on the price-dividend ratio dominates the positive sign on dividends; therefore, we have $(\kappa_1 A_{z1} + k_{d\xi} A_y) < 0$, which is consistent with Sangiorgi and Santoro (2005), who use a representative agent model. When participation is sufficiently restricted, the absolute value of the price of risk and the amount of risk can be much higher in the limited participation model than in the representative agent model.

4 Parametrization

We present the parameter values in Table 1. The inverse of the intertemporal elasticity of substitution (σ) implies that the utility in consumption has a logarithmic form. The parameter φ is set to 1.5, which implies that the Frisch elasticity of the labor supply is 2/3. When technology is set to unity in the steady state ($A = 1$), the steady-state equality of consumption for each type implies that the same hours are worked by both types ($N^o = N^r = N$) in this state.

The elasticity of substitution among intermediary goods (ϵ) is set to 11, implying a net markup ($1/(\epsilon - 1)$) of 10 percent, which is standard in the literature. The Calvo parameter of price adjustment is 0.80, which implies an average duration of a price spell of 5 quarters. This is a value similar to the value chosen by Christiano et al. (2011). For simplicity, we consider a Taylor rule that focuses only on inflation with a coefficient of 1.1, which satisfies the Taylor principle. The share of non-Ricardian households is set to 0.39, which is at the lower end of the estimates.[11] The persistence and standard deviation of the monetary policy shock are set to 0.75 and 0.005, respectively, in line with Carrillo et al. (2007) and Rudebusch (2006).

[11] Gali et al. (2007) and De Graeve et al. (2010) employ 0.5 and 0.6 for λ, respectively. Campbell and Mankiw (1991) use 35 percent, while Fuhrer (2000) employs the estimate in the range of 26-29 percent depending on the econometric method used.

Table 1
Parametrization

σ=1	$\beta = 0.99$	$\phi_\pi = 1.1$
$\epsilon = 11$	$\varphi = 1.5$	$\rho_\xi = 0.75$
$\theta = 0.80$	$\lambda = 0.39$	$\sigma_\xi = 0.005$

5 Results

5.1 REPRESENTATIVE AGENT MODEL

To better clarify the functioning of the limited participation model, we first explain the effects of an unanticipated increase in the nominal interest rate due to a monetary policy shock in the representative agent model ($\lambda = 0$). According to the Taylor principle, a contractionary monetary policy shock leads to a higher real interest rate, which causes Ricardian households to delay their consumption from the present to the future. The negative wealth effect of the monetary policy shock also causes a decline in leisure time (normal good) and induces Ricardians to work more within a fixed time frame. Hence, the labor supply shifts out, depressing the real wage.

As many of the firms face price rigidity, not all of them can reduce prices when demand falls. As a result, those firms that cannot reset their prices will decrease production and demand less labor, shifting labor demand leftward and further depressing real wages. Price rigidity is therefore necessary for monetary policy shocks to have real effects.

With our baseline calibration, the standard representative agent model delivers an equity premium of approximately 0.3 percent. This finding is consistent with the literature (see de Paoli et al. (2010) and Wei (2009)). Unless the model is enriched with capital, Jermann (1998)-type capital adjustment costs and a counterfactually high persistence of the monetary policy shock, the equity premium remains small. Because of the mildly persistent monetary policy shock (our baseline calibration), the equity premium is closer to one than zero.

5.2 LIMITED PARTICIPATION MODEL

We now divide the population into Ricardian and non-Ricardian households ($\lambda > 0$). Figure 2 displays the sensitivity of output, inflation, dividends and the equity premium to the share of non-Ricardian households. In each graph, $\lambda = 0$ delivers the standard representative agent model (only Ricardian households), where the equity premium is approximately 1 percent (see the bottom-right panel, *ep*). The sensitivity of output, inflation and the growth rate of dividends to a monetary policy shock (see the subplots denoted as A_y, A_π and $\kappa_{d\xi}A_y$, respectively) increases with the share of non-Ricardian households in the population. This can be explained as follows. Consider a contractionary monetary policy shock that leads to a rise in real interest rates and curbs Ricardian expenditures. With rigid prices, the monetary tightening also leads to decreases in labor demand, marginal costs (real wages) and thus the wage income of non-Ricardians. However, at the same time, it leads to increases in profits, endogenously redistributing income from non-Ricardians to Ricardians.[12] The latter channel exists due to the price rigidity effect establishing the link between non-Ricardians' demand (based on their wage income) and real interest rates.

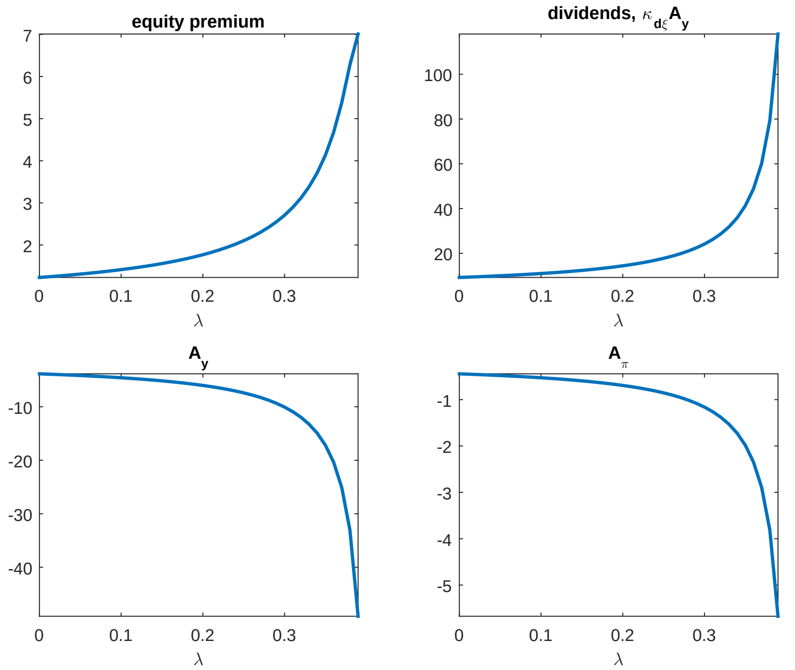
With a higher share of non-Ricardians, monetary policy is more successful at curtailing aggregate demand through increases in the real interest rate. With a stronger redistribution of income from non-Ricardians to Ricardians, the ownership of firms is more concentrated. This concentration decreases the consumption of Ricardians, whose consumption is susceptible to changes in dividend income.[13] In addition, asset returns positively comove with the growth rate of dividends. As a result, a positive connection emerges between the share of non-Ricardians and the equity premium.

Specifically, a restrictive monetary shock today ($\xi_t > 0$) leads to a decline in the price-dividend ratio (z_t) (in equation 5), which increases the next-period returns (r_{t+1}) (see equation 4) as long as $A_{z1} < 0$, which is satisfied in our baseline calibration. With

[12] Real dividends are calculated as the difference between output minus the wage bill in real terms: $D_t = Y_t - \frac{W_t}{P_t}N_t = Y_t(1 - \frac{W_t}{P_t})$, where the second equality assumes a one-to-one production function with technology normalized to one.
The equation that describes the connection between the real wage ($w_t = (\sigma + \varphi)y_t$ in loglinear terms) and output shows that a unit change in output will induce more than a one-unit change in the real wage as long as the inverse of the Frisch elasticity is not zero ($\varphi > 0$). Even when $\varphi > 0$, an intertemporal elasticity of substitution lower than one (equivalent to $\sigma > 1$) will lead to a response in the real wage that is in excess of unity. Hence, returning to the dividend equation, we can claim that the fall in wages has a larger effect on dividends than the corresponding fall in output. Overall, the total effect will be a rise in dividends following a contractionary monetary policy shock.

[13] The dividend income of Ricardians is increasing in the share of non-Ricardian households for a given level of aggregate dividends ($D_t^o = D_t/(1 - \lambda)$).

Figure 2
Sensitivity of A_y, A_π, $\kappa_{d\xi}A_y$ and the equity premium (*ep*) relative to the share of non-Ricardian households (λ)



Notes: A_π is annualized. The ep is measured as an annualized percentage. Values of λ higher than 0.39 are excluded, as the equilibrium is indeterminate for that region.

a sufficiently high share of non-Ricardians ($\lambda = 0.39$), we obtain a large equity premium ($ep = 7.0089$ percent) and a high standard deviation of equity returns (30.81 percent). These values are reasonably close to the 6.33 and 19.42 (in annualized terms), respectively, reported by Bansal and Yaron (2004) for the market portfolio using postwar US data. Our model is also successful in reproducing the empirical value of the Sharpe ratio (the ratio of the mean of the equity premium and the standard deviation of the equity return), which is approximately 0.2-0.3 in the postwar US data and 0.32 in our model.

A shortcoming of our model is that it produces the risk-free rate puzzle. When the share of non-Ricardians is sufficiently high, the volatility of both the consumption of Ricardians and the stochastic discount factor exhibits three times more volatility in the risk-free rate in our model than its empirical equivalent. An extension of our model with further frictions, such as wage rigidity, capital accumulation with adjustment costs and technology shocks, could also solve the risk-free rate puzzle. In this paper, however, we include the smallest number of frictions to clearly illustrate the mechanisms leading to the redistribution of income between the two types of households and to the high equity premium.

6 Sensitivity Analysis

We present the results of our sensitivity analysis in Figure 3. In particular, we investigate the sensitivity of our main result to the lower Frisch elasticity, the lower average duration of price rigidity and a larger coefficient on inflation in the Taylor rule.

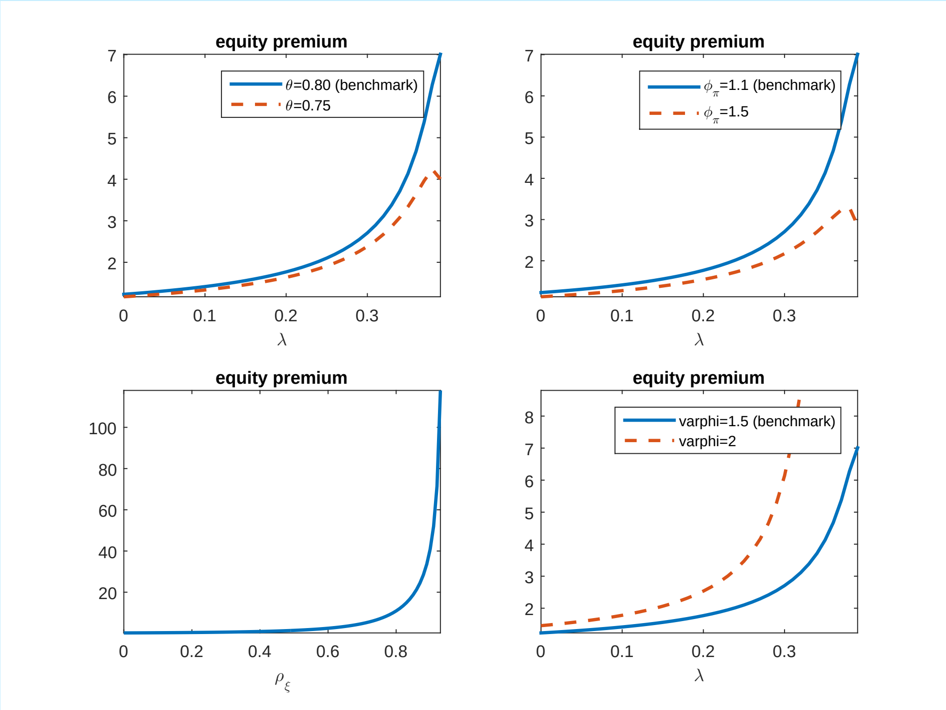
The inverse of the Frisch elasticity (φ). When the labor supply is less elastic (i.e., when Frisch elasticity is lower, φ increases from 1.5 to 2), we expect lower flexibility of labor in the case of negative shocks. We also expect that the equity premium is larger. When setting $\varphi = 2$, the equity premium is higher by more than 1 percentage point, but the determinacy region shrinks. In this case, the equity premium is the highest at $\lambda = 0.32$, and the highest value of λ for which the equilibrium is determinate is 0.33.

Calvo parameter of price rigidity (θ). With greater price rigidity, we expect stronger monetary policy shocks. In this scenario, we consider a lower average duration of price rigidity than in the baseline calibration (4 quarters instead of the 5 quarters assumed in the baseline). With lower price rigidity, the equity premium declines to 3.30 percent, which is nevertheless more than three times larger than that in the representative agent model.

Coefficient of inflation in the Taylor rule (ϕ_π). With a higher coefficient on inflation in the Taylor rule, we expect the effects of the monetary policy shock to be more contained and thus equity premium to be substantially reduced. The figure shows the effects of increasing ϕ_π from 1.1 to 1.5. The equity premium is halved with an increase in ϕ_π. When $\phi_\pi \rightarrow \infty$, the monetary policy shock is completely neutralized (no relative price distortions), and we return to the case of fully flexible prices in which monetary policy has no effect. Therefore, the equity premium is zero in such an economy.

Persistence of the monetary policy shock (ρ_ξ). When the persistence of the monetary policy shock is higher, we expect the real effects of the shock to be stronger and the equity premium to be larger. This expectation is confirmed by Figure 3, which shows that the equity premium can be counterfactually high when the monetary policy shock is very persistent. The figure also tells us that some moderate level of persistence is necessary for the equity premium to be in the empirically relevant range.

Figure 3
Sensitivity checks



Notes: A_π is annualized. The equity premium is measured as an annualized percentage. Values of λ higher than 0.6 are excluded, as they deliver implausibly high equity premia and are not in line with empirical evidence.

7 GMM Estimation of the Extended Model

We extend our baseline model with the physical capital of Jermann (1998)-type capital adjustment costs, habits in consumption, Epstein-Zin preferences, and a more realistic fiscal setup[14] and estimate our extended model with the GMM toolbox of Andreasen et al. (2018) using the following quarterly US macroeconomic and financial time series in 1960Q1-2007Q1: i) per capita consumption growth, dC_t; (d denotes the temporal difference operator); ii) one-quarter nominal interest rate, i_t; iii) per capita hours growth, dL_t; iv) growth rate of real wage $d(W_t/P_t)$; v) inflation, Π_t; vi) slope of the term structure proxied by the difference between the 10-year nominal interest rate, $i_t^{(40)}$, and the one-quarter nominal interest rate, i_t; vii) 10-year nominal term premium from Adrian et al. (2013); viii) growth rate of labor tax revenue per GDP ($d(\tau_t W_t L_t/Y_t)$); and ix) leveraged excess return on US stocks. The online appendix provides more information about the data used in the estimation and describes the extended model, including its derivation.

As in Andreasen et al. (2018) and Bretscher et al. (2020), we focus on three types of unconditional moments for the GMM estimation: i) the sample means $m_1(y_t) = y_t$, the contemporaneous covariances $m_2(y_t) = vech(y_t y_t^{'})$, and the own autocovariances, $m_3(y_t) = \{y_{i,t} y_{i,t-k}\}_{i=1}^{n_y}$ for $k = 1$ and $k = 5$. As a result, the set of moments we use in the estimation is given by $m(y_t) = [m_1(y_t)\ m_2(y_t)\ m_3(y_t)]^{'}$.

Letting θ denote the structural parameters, the GMM estimator is given by:

$$\arg\min_{\theta\in\Theta} \left(\frac{1}{T}\sum_{t=1}^{T} q_t - E(q_t(\theta)) \right)^{'} W \left(\frac{1}{T}\sum_{t=1}^{T} q_t - E(q_t(\theta)) \right). \tag{7}$$

In equation (7), W is a positive definite weighting matrix, $\frac{1}{T}\sum_{t=1}^{T} q_t$ represents data moments, and $E(q_t(\theta))$ are moments computed from the model. We employ a standard two-step procedure to implement the GMM. We set $W_T = diag(\widehat{S}^{-1})$ in the first step in order to to obtain $\widehat{\theta}^{(1)}$ where $\hat{S}$ denotes the long-run variance-covariance matrix of $\frac{1}{T}\sum_{t=1}^{T} q_t$ when centered around its sample mean. In the second step, we obtain $\widehat{\theta}^{(2)}$ using the optimal weighting matrix $W_T = \widehat{S}^{-1}_{\widehat{\theta}^{(1)}}$ where the diagonal of $\widehat{S}^{-1}_{\widehat{\theta}^{(1)}}$ includes the long-run variance of our moments recentered around $E\left(q_t(\widehat{\theta}^{(1)})\right)$. The long-run variances in both steps are estimated with the Newey-West approach with five lags; our results are robust to the inclusion of, e.g., ten lags.

We present the parameters estimated by the GMM in Tables 2 and 3. The column titles with a star indicate the model version without capital adjustment costs. To summarize, we note that the majority of our parameter estimates are in line with those presented in Andreasen et al. (2018) and Bretscher et al. (2020). Similar to the findings of Andreasen et al. (2018) and Bretscher et al. (2020), the curvature parameter of recursive preferences, α^{EZ}, is estimated rather imprecisely.

Regarding the estimates of the curvature parameter, we make the two following observations. First, the models are estimated with lower relative risk-aversion coefficients, similar to the findings of Horvath et al. (2019) (see the implied CRRA in the range of 31-37 for the time-varying and constant debt models) rather than earlier papers (see Rudebusch and Swanson (2012) with a value of CRRA at 110 in their best fit calibration and Andreasen (2012) with the value of 168). Nevertheless, the estimated level of risk aversion is high, which is needed to match the bond premium and is a feature of many recent macrofinance papers (see, e.g., Andreasen (2012), Andreasen et al. (2018), Rudebusch and Swanson (2012) and Li and Palomino (2014)).[15] Second, the constant debt setup induces higher risk premia, and therefore, constant debt models are estimated with relatively lower curvature as well as CRRA parameters. This result confirms the findings of Horvath et al. (2019).

The estimated share of non-Ricardians (λ) is higher for the model versions without capital adjustment costs. The capital adjustment cost parameter (χ_K) is estimated to be somewhat higher than the value used by de Paoli et al. (2010). The share

[14] We assume either constant or time-varying debt.

[15] There are several possible explanations to justify the high risk aversion, see the discussion in Rudebusch and Swanson (2012).

Table 2
GMM estimates of the models I

Parameters and steady-states	Time-varying debt	Time-varying debt*	Constant debt	Constant debt*
Household				
$\widetilde{\beta}$	0.9989 0.0024	0.9981 0.0027	0.9912 0.0039	0.9948 0.0086
σ	1.9996 0.48	1.9982 0.37	2.0046 0.46	2.065 0.48
φ	2.8499 0.99	2.8547 0.96	2.7125 0.13	2.6571 0.29
α^{EZ}	−79.3370 53.27	−89.6291 55.81	−62.1382 33.34	−69.4397 36.12
N	0.3490 0.0048	0.3152 0.0085	0.3882 0.00062	0.3611 0.0027
CRRA (implied)	39.95	47.38	30.73	34.51
λ	0.3321 0.0398	0.3719 0.0463	0.3182 0.0351	0.3641 0.0571
h_o	0.73 0.019	0.85 0.023	0.72 0.038	0.86 0.014
h_r	0.71 0.024	0.79 0.026	0.74 0.015	0.81 0.028
Firm				
α	0.3454 0.0051	0.3475 0.0055	0.3541 0.0039	0.3523 0.0047
χ^P	321.05 0.0027	358.53 0.0033	342.31 0.0065	352.16 0.0074
χ^K	0.041 0.0027	–	0.053 0.0015	–
Monetary policy				
ρ_I	0.7305 0.33	0.7513 0.41	0.7334 0.26	0.8712 0.28
g_π	0.5298 3.98	0.5532 3.36	0.5197 1.51	0.5216 1.53
g_y	0.9299 0.05	0.9132 0.04	0.9224 0.03	0.9305 0.03
Persistence and standard deviations of shocks				
ρ_i	0.7665 0.0053	0.8352 0.0065	0.8174 0.0037	0.8218 0.0051
σ_a	0.0534 0.0028	0.0521 0.0013	0.0558 0.0014	0.0561 0.0012
σ_i	0.0231 0.0202	0.0336 0.0519	0.0371 0.0285	0.0358 0.0325
σ_d	0.0063 0.0046	0.0068 0.0035	0.0051 0.0143	0.0065 0.0312

*Notes: Numbers below the parameter estimates denote the standard error of the estimate in percent. – means that χ_K is not estimated in the absence of capital adjustment costs. * indicates a model version without capital adjustment costs.*

Table 3
GMM estimates of the models II

Parameters and steady-states	Time-varying debt	Time-varying debt*	Constant debt	Constant debt*
Fiscal policy rule and persistence of fiscal shocks				
ρ_g	0.9401 1.9	0.9401 2.4	0.9829 2.11	0.9601 3.25
ρ_τ	0.9602 0.0055	0.9802 0.0145	– –	– –
$\rho_{\tau b}$	0.0599 0.0021	0.0631 0.0151	– –	– –
$\rho_{\tau y}$	0.9602 0.33	0.9902 0.26	– –	– –
Standard deviation of fiscal shocks				
σ_g	0.011 0.0031	0.018 0.0162	0.0094 0.0029	0.0099 0.0062
σ_τ	0.0033 0.0064	0.0037 0.0171	– –	– –

*Notes: Numbers below the parameter estimates denote the standard error of the estimate in per cent. — indicates those parameters which do not appear in the constant debt model. * denotes the models without capital adjustment cost.*

of capital in production (or, alternatively, in income), α, is close to one-third, which is a standard value in the real business cycle literature. The estimated share of hours worked in the total time allocation, N, is in the range of 0.33-0.38. The latter is consistent with the conventional value of 0.33 used in the real business cycle literature.

The habit formation parameter for Ricardians and non-Ricardians is also estimated (denoted as h_o and h_r, respectively). We find that habit formation is typically higher in model versions without capital adjustment costs. The omission of capital adjustment costs implies that the model tries to capture the persistence in the data by somewhat higher values of the habit formation parameter.

The estimated high value of the Rotemberg adjustment cost parameter (χ_p) does not necessarily indicate a high price rigidity but points to the fact that some real frictions are missing from the model. The introduction of further real rigidities (such as a specific labor market) could help reduce the reliance on a high value of price rigidity in the matching persistence in the data.

The estimated value of the standard deviation of the dividend payout shock, σ_d, is reasonably close to the value reported by Croce (2014) for both fiscal setups. The estimates of the parameters in the Taylor rules as well as the monetary policy shock are in line with those of Rudebusch (2002) and Andreasen (2012). The estimate of the persistence and the size of the technology shock is close to the GMM estimates of Andreasen (2012).

Examining the estimates of the fiscal processes in Table 3, we find that the AR(1) term and the standard deviation for the government spending process are reasonably close to the single-equation estimates in the literature (see, e.g., King and Rebelo (1999)). The estimated coefficients in the tax rule are close to Leeper et al. (2010) and Zubairy (2014), who estimate middle-size DSGE models using Bayesian methods.

Some parameters and steady-state quantities are not estimated but calibrated as follows. ε is the elasticity of substitution among intermediary goods and is calibrated to six. The steady-state markup is given by $\varepsilon/(\varepsilon-1)$. The steady-state marginal cost ($\overline{mc}$) is the inverse of the markup. The $\gamma_b = 2.4$ is consistent with a yearly debt-to-GDP ratio of 60 percent. The steady-state inflation rate is zero ($\Pi^* = 1$).

The government spending-to-GDP ratio is calibrated to 20 percent, which is in line with postwar US data. The steady-state tax rate implied by the government budget constraint is 36 percent. The leverage parameter, ϕ_{lev}, is calibrated to two, as in Croce (2014), and is on the lower side of the empirical estimates. Model versions that do not include capital adjustment costs are invoked by setting $\chi_K = 300000$.

8 Results from the extended model

8.1 MACRO AND FINANCE MOMENTS FROM THE EXTENDED MODEL

The extended model matches a selection of macroeconomic and finance moments calculated using US data from 1960-2007 (see Table A1 in online Appendix D).[16] Beyond macro and finance variables, the models' fit is assessed on the basis of fiscal moments such as the unconditional correlation of the labor tax revenue and first-order autocorrelation of labor tax revenue. The models with either constant or time-varying government debt exhibit modest fit to a series of macroeconomic and financial moments.

8.2 THE INTERACTION OF CONSUMPTION HABITS AND LIMITED ASSET MARKET PARTICIPATION IN THE EXTENDED MODEL

It is well known that consumption habits raise the variability of short-term interest rates due to the aversion of Ricardians against sudden changes in the consumption stream (see, e.g., Jermann (1998)). It is important to emphasize that non-Ricardian behavior raises not only the strength of the comovement between Ricardian consumption and dividends (generating a high equity premium) but also increases variability in dividends, which makes Ricardian consumption even more volatile, inducing higher precautionary savings. Specifically, the introduction of LAMP nearly doubles the standard deviation of the dividends (not reported in the moments table), raises precautionary savings and thus reduces the variability of the short-term interest rate. This property of LAMP is also valid in the model of Menna and Tirelli (2014).

[16] We focus on data from before the great recession to avoid complications posed by the fact that the US monetary policy rate reached the zero lower bound at the end of 2008.

9 Concluding Remarks

We examine the interactions among monetary policy, financial markets and income inequality in this paper. To motivate our theoretical model, we start with an empirical exercise. First, we estimate a VAR model on US data in 1960q1-2007q1 and find that a recursively identified monetary restriction leads to an increase in the equity premium. This prediction is in line with the prediction of our theoretical model.

Second, we develop a simple labor-only New Keynesian model with heterogeneous agents (Ricardian vs. non-Ricardian households) and show that monetary policy shocks are important drivers of equity premia. This is so when they cause a redistribution of income from non-Ricardian to Ricardian households and when risky assets are concentrated in the hands of relatively few investors whose consumption strongly covaries with asset returns. In our model, a contractionary monetary policy shock causes the redistribution of income from non-Ricardians to Ricardians in the form of higher dividends.

Third, we augment our simple New Keynesian model with a more realistic fiscal setup, capital adjustment costs, and Epstein-Zin preferences to jointly explain the equity premium and the term premium in the yields of long-term nominal bonds. The model's parameters are estimated on US data from 1960-2007 by the GMM using a third-order accurate solution of the model. In line with other studies, we find that these frictions help produce high equity and bond premia as long as risk aversion is sufficiently high and temporary technology shocks are also included in the model.

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Online Appendix A

SUMMARY OF LOGLINEAR EQUILIBRIUM CONDITIONS

This section provides a loglinear solution to the model.

The loglinear equilibrium conditions are detailed below and are, in fact, similar to those in Bilbiie (2008) and Gali et al. (2007). We differ from Gali et al. (2007) to the extent that we exclude capital with adjustment costs and the government sector. Our exclusion of capital facilitates an analytical solution and the identification of the channels that contribute to the high equity premium.

Please note that in all derivations below, the inverse of the intertemporal elasticity of substitution is chosen to be one (log utility in consumption): $\sigma = 1$.

The intratemporal conditions for type $i = r, o$

$$w_t = \sigma c_t^i + \varphi n_t^i,$$

which can be aggregated to

$$w_t = \sigma c_t + \varphi n_t,$$

using the consumption and labor aggregators, respectively,

$$c_t = \lambda c_t^r + (1 - \lambda) c_t^o,$$

$$n_t = \lambda n_t^r + (1 - \lambda) n_t^o.$$

The budget constraint of the non-Ricardian household is

$$c_t^r = w_t + n_t^r.$$

The intertemporal Euler equation of Ricardians is given by

$$\sigma(c_t^o - E_t c_{t+1}^o) = -(dR_t - E_t \pi_{t+1}). \tag{A1}$$

The production function reads as follows:

$$y_t = a_t + n_t.$$

The aggregate resource constraint (market clearing) is

$$y_t = c_t.$$

The New Keynesian Phillips curve (NKPC) is given by

$$\pi_t = \beta E_t \pi_{t+1} + \kappa mc_t,$$

where mc_t represents the real marginal cost, and κ is the slope of NKPC. The system is closed by adding a linear Taylor rule of the form

$$dR_t = \phi_\pi \pi_t + \xi_t.$$

The model can be solved using the method of undetermined coefficients. Let us postulate that output and inflation are given as a linear function of the monetary policy shock:

$$y_t = A_y \xi_t = y_\xi \xi_t,$$

$$\pi_t = A_\pi \xi_t = \pi_\xi \xi_t,$$

where $A_y = y_\xi$ and $A_\pi = \pi_\xi$ are coefficients to be determined.

PROOF OF PROPOSITION 1. DERIVATION OF $A_\pi = \pi_\xi$

The NKPC is given by

$$\begin{aligned}\pi_t &= \beta E_t \pi_{t+1} + \kappa mc_t,\\ &= \beta E_t \pi_{t+1} + \kappa(\sigma c_t + \varphi n_t - a_t),\\ &= \beta E_t \pi_{t+1} + \kappa(\sigma y_t + \varphi n_t + \varphi a_t - \varphi a_t - a_t),\\ &= \beta E_t \pi_{t+1} + \kappa[(\sigma + \varphi) y_t - (1+\varphi) a_t].\end{aligned}$$

The second line makes use of the fact that the marginal cost equals the real wage minus the technology shocks (in linear terms). The third line uses the market clearing and adds and subtracts φa_t. The fourth line makes use of the production function $y_t = a_t + n_t$. For the remainder of the derivation, we can ignore the technology shock (a_t), as our focus is on the monetary policy shock.

First, let us rewrite the NKPC as a function of the monetary policy shock:

$$\begin{aligned}\pi_t &= \beta \pi_\xi \rho_\xi \xi_t + \kappa(\sigma + \varphi) A_y \xi_t,\\ &= \left\{\beta \pi_\xi \rho_\xi + \kappa(\sigma+\varphi) A_y\right\} \xi_t,\end{aligned}$$

where A_y is calculated below.

Matching coefficients,

$$\pi_\xi = \beta \pi_\xi \rho_\xi + \kappa(\sigma+\varphi) y_\xi,$$

$$\pi_\xi = \frac{\kappa(\sigma+\varphi) y_\xi}{1-\beta\rho_\xi}. \tag{A2}$$

PROOF OF PROPOSITION 1. DERIVATION OF $A_Y = Y_\xi$

The separate labor supply decision of non-Ricardian households is given by the following linear intratemporal condition:

$$c_t^r + \varphi n_t^r = w_t,$$

which we express for n_t^r as

$$n_t^r = \varphi^{-1}(w_t - c_t^r),$$

which we substitute for n_t^r in the loglinear budget constraint of non-Ricardians, while also making use of the aggregate intratemporal condition:

$$c_t^r = w_t + n_t^r,$$

and

$$\sigma c_t^r + \varphi n_t^r = w_t.$$

The previous condition can be expressed for c_t^r as

$$c_t^r = [w_t] + \varphi^{-1}([w_t] - \sigma c_t^r),$$

and we can substitute the aggregate intratemporal condition for the real wage in squared brackets:

$$c_t^r = [\sigma c_t + \varphi n_t] + \varphi^{-1}([\sigma c_t + \varphi n_t] - \sigma c_t^r).$$

The c_t^r terms can be collected on the left-hand side as follows:

$$c_t^r\left(1 + \frac{\sigma}{\varphi}\right) = \sigma c_t + \varphi n_t + \varphi^{-1}\left(\sigma c_t + \varphi n_t\right).$$

Then, it follows that the consumption of non-Ricardians is a function of the aggregate variables of the model:

$$c_t^r = \frac{\sigma(1+\varphi)}{\varphi+\sigma}c_t + \frac{(1+\varphi)\varphi}{\varphi+\sigma}n_t. \tag{A3}$$

Let us define the forward operator as L^{-1} and apply $1-L^{-1}$ to both sides of the previous equation:

$$c_t^r - E_t c_{t+1}^r = \frac{\sigma(1+\varphi)}{\varphi+\sigma}(c_t - E_t c_{t+1}) + \frac{(1+\varphi)\varphi}{\varphi+\sigma}(n_t - E_t n_{t+1}). \tag{A4}$$

Recall the consumption aggregator, and apply the $1-L^{-1}$ operator to obtain

$$c_t - E_t c_{t+1} = \lambda(c_t^r - E_t c_{t+1}^r) + (1-\lambda)(c_t^o - E_t c_{t+1}^o).$$

Then, using equation (A4) leads to

$$\begin{aligned} c_t - E_t c_{t+1} = {} & \frac{\lambda\sigma(1+\varphi)}{\varphi+\sigma}(c_t - E_t c_{t+1}) + \frac{\lambda(1+\varphi)\varphi}{\varphi+\sigma}(n_t - E_t n_{t+1}) \\ & + (1-\lambda)(c_t^o - E_t c_{t+1}^o). \end{aligned}$$

Recall the Ricardian Euler equation:

$$\sigma(c_t^o - E_t c_{t+1}^o) = -(dR_t - E_t \pi_{t+1}),$$

where $dR_t = R_t - R$ is the deviation of the nominal interest from its steady state. The Ricardian Euler equation can be inserted into the previous equation to obtain

$$\begin{aligned} c_t - E_t c_{t+1} = {} & \frac{\lambda\sigma(1+\varphi)}{\varphi+\sigma}(c_t - E_t c_{t+1}) + \frac{\lambda(1+\varphi)\varphi}{\varphi+\sigma}(n_t - E_t n_{t+1}) \\ & - \frac{(1-\lambda)}{\sigma}(dR_t - E_t \pi_{t+1}). \end{aligned}$$

Using the market clearing and the production function, we obtain

$$\begin{aligned} y_t - E_t y_{t+1} = {} & \frac{\lambda\sigma(1+\varphi)}{\varphi+\sigma}(y_t - E_t y_{t+1}) + \frac{\lambda(1+\varphi)\varphi}{\varphi+\sigma}(y_t - E_t y_{t+1}) \\ & - \frac{\lambda(1+\varphi)\varphi}{\varphi+\sigma}(a_t - E_t a_{t+1}) - \frac{(1-\lambda)}{\sigma}(dR_t - E_t \pi_{t+1}). \end{aligned}$$

The previous function can be rewritten as (after inserting the Taylor rule for dR_t). After simplifications, we obtain

$$\begin{aligned} & [1-\lambda(1+\varphi)]y_t = [1-\lambda(1+\varphi)]E_t y_{t+1} \\ & - \frac{\lambda(1+\varphi)\varphi}{\varphi+\sigma}(a_t - E_t a_{t+1}) - \frac{(1-\lambda)}{\sigma}(\phi_\pi \pi_t + \xi_t - E_t \pi_{t+1}). \end{aligned}$$

Let us define

$$\Gamma \equiv 1 - \lambda(1+\varphi),$$

and use the guesses and the AR(1) property of the shock for y_{t+1} and π_{t+1} to rewrite the previous equation as

$$\begin{aligned} y_t = {} & \frac{[1-\lambda(1+\varphi)]}{\Gamma} y_\xi \rho_\xi \xi_t \\ & - \frac{\lambda(1+\varphi)\varphi}{\Gamma(\varphi+\sigma)}(a_t - E_t a_{t+1}) - \frac{(1-\lambda)}{\Gamma\sigma}(\phi_\pi \pi_t + \xi_t - \pi_\xi \rho_\xi \xi_t). \end{aligned}$$

Here, Γ is the same as that in Proposition 1.

Henceforth, we can ignore the technology component, as our focus is on the monetary policy shock. We can also substitute π_t in the undetermined coefficient solution from equation (A2) to obtain

$$y_t = \left[\frac{[1-\lambda(1+\varphi)]}{\Gamma} y_\xi \rho_\xi - \frac{(1-\lambda)}{\sigma\Gamma}(\phi_\pi - \rho_\xi)\frac{\kappa(\sigma+\varphi)y_\xi}{1-\beta\rho_\xi} - \frac{(1-\lambda)}{\sigma\Gamma}\right]\xi_t.$$

In the next step, we match coefficients such that the expression in the squared brackets is made equal to y_ξ. After the expression in [] is matched, we collect all the terms in y_ξ:

$$y_\xi \left\{ 1 - \frac{[1-\lambda(1+\varphi)]\rho_\xi}{\Gamma} + \frac{(1-\lambda)(\phi_\pi - \rho_\xi)}{\sigma\Gamma} \frac{\kappa(\sigma+\varphi)}{1-\beta\rho_\xi} \right\} = -\frac{(1-\lambda)}{\sigma\Gamma},$$

which can be written as (with a common denominator)

$$y_\xi \left\{ \frac{\Gamma(1-\beta\rho_\xi)\sigma[1-(1-\lambda(1+\varphi))\rho_\xi] + (1-\lambda)(\phi_\pi - \rho_\xi)\kappa(\sigma+\varphi)}{\sigma\Gamma(1-\beta\rho_\xi)} \right\} = -\frac{(1-\lambda)}{\sigma\Gamma}.$$

Therefore, the coefficient we are looking for is the following:

$$y_\xi = -\frac{(1-\lambda)(1-\beta\rho_\xi)}{\Gamma(1-\beta\rho_\xi)\sigma - [1-\lambda(1+\varphi)]\rho_\xi(1-\beta\rho_\xi)\sigma + (1-\lambda)(\phi_\pi - \rho_\xi)\kappa(\sigma+\varphi)},$$

which is the same as in Proposition 1 ($\sigma = 1$ because of the logarithm of the consumption in the utility function)

Online Appendix B

This online appendix provides a loglinear solution to the price-dividend ratio and the equity premium.

PROOF OF PROPOSITION 3

We provide details on the derivation of A_{z1}, A_c and $\kappa_{d\xi}$ in Proposition 2.

The loglinear version of the stochastic discount factor is given by

$$sdf_{t,t+1} = -\sigma \Delta c^o_{t+1}.$$

To establish a connection between Ricardian consumption and aggregate variables, we use the consumption aggregator of the two types and equation (A3) to derive

$$c^o_t = \frac{1}{1-\lambda} c_t - \frac{\lambda(1+\varphi)}{1-\lambda} n_t. \tag{A5}$$

Then, it follows that

$$\Delta c^o_{t+1} = \frac{1-\lambda(1+\varphi)}{1-\lambda} \Delta y_{t+1}.$$

Thus, the sdf can be expressed as

$$\begin{aligned} sdf_{t,t+1} &= -\sigma \Delta c^o_{t+1} = -\sigma \left\{ \frac{1-\lambda(1+\varphi)}{1-\lambda} \right\} \Delta y_{t+1}, \\ &= -\sigma A_c A_y (\xi_{t+1} - \xi_t), \\ \text{where } A_c &\equiv \frac{1-\lambda(1+\varphi)}{1-\lambda}, \end{aligned}$$

and $A_y = y_\xi$ is derived in online Appendix A.
Taking expectations of the previous equation we arrive at

$$E_t sdf_{t,t+1} = \sigma A_c A_y (1-\rho_\xi) \xi_t.$$

Divididens can be expressed as

$$d_t = \kappa_{d\xi} n_t,$$

where

$$\kappa_{d\xi} = 1 - \frac{W}{1-W}(\sigma + \varphi),$$

and $W = \frac{\epsilon - 1}{\epsilon}$.

Recall from the main text that the return on asset i is given by

$$rr_{i,t+1} = \beta A_{z1} \xi_{t+1} - A_{z1} \xi_t + \Delta d_{i,t+1}, \tag{A6}$$

where real dividends can be expressed as

$$d_t = \kappa_{d\xi} A_y \xi_t.$$

After linearizing the asset Euler equation and the expectations, we obtain (using $E_t \xi_{t+1} = \rho_\xi \xi_t$):

$$\begin{aligned} 0 &= E_t rr_{i,t+1} + E_t sdf_{t,t+1} \\ &= (\beta \rho_\xi - 1) A_{z1} \xi_t - (1-\rho_\xi) \kappa_{d\xi} A_y \xi_t + A_c A_y (1-\rho_\xi) \xi_t. \end{aligned}$$

Therefore, for the previous expression to be equal to zero, the sum of the coefficients multiplying ξ_t must satisfy

$$A_{z1} = \frac{A_c A_y (1-\rho_\xi)}{1-\beta\rho_\xi} - \frac{(1-\rho_\xi) A_y \kappa_{d\xi}}{1-\beta\rho_\xi}.$$

Hence, the return on equity can be written, using equation (A6), as

$$\begin{aligned} rr_{i,t+1} = & -\frac{\beta(1-\rho_\xi)\kappa_{d\xi}A_y}{(1-\beta\rho_\xi)}\xi_{t+1} + \frac{\beta\sigma A_c A_y (1-\rho_\xi)}{(1-\beta\rho_\xi)}\xi_{t+1} \\ & - A_{z1}\xi_t + \kappa_{d\xi}A_y \Delta\xi_{t+1}, \end{aligned}$$

PROOF OF PROPOSITION 4

We start with the definition of the equity risk-premium, which is the negative of the conditional covariance between the linearized expected value of the stochastic discount factor and the linearized expected value of the return on the asset:

$$\begin{aligned} ep_t &= A_c A_y cov_t(\xi_{t+1}, rr_{t+1}) \\ &= A_c A_y (\kappa_1 A_{z1} + k_{d\xi} A_y) \times \sigma_\xi^2, \end{aligned}$$

where $A_c A_y(\kappa_1 A_{z1} + k_{d\xi} A_y)$ is the price of risk and σ_ξ^2 is the quantity of risk. In the second row of the expression above we used equations (4), (5) and (6). Through the derivation we ignored constants and time-t terms, which would be irrelevant because we study the conditional covariance in a stochastic setting based on a time-t information set.

Online Appendix C – Short Description of the Extended Model

First, we discuss the problem of Ricardian households. They maximise the continuation value of its utility (V) which has the Epstein-Zin form and follows the specification of Rudebusch and Swanson (2012):

$$V_t = \begin{cases} U^o(C_t^o, N_t^o) + \beta \left[E_t V_{t+1}^{1-\alpha}\right]^{\frac{1}{1-\alpha}} \text{ if } U^o(C_t^o, N_t^o) \geq 0 \\ U^o(C_t^o, N_t^o) - \beta \left[E_t(-V_{t+1})^{1-\alpha}\right]^{\frac{1}{1-\alpha}} \text{ if } U^o(C_t^o, N_t^o) < 0. \end{cases} \tag{A7}$$

where E_t is the expectation operator representing expectations conditional on period-t information and β is the discount factor. $U^o(C_t^o, N_t^o)$ is instantenous utility of the optimiser households. Only optimiser households have Epstein-Zin curvature over the continuation value of their utility.

The instantenous utility function of type $i \in \{o, r\}$ household (either Optimiser (OPT), o or Rule-of-Thumb (ROT), r)[17], can be specified, after the introduction of external habit formation, as:

$$U_t^i = \frac{(C_t^i - h_i \bar{C}_{t-1}^i)^{1-\sigma} - 1}{1-\sigma} - \frac{(N_t^i)^{1+\varphi}}{1+\varphi}, \tag{A8}$$

where C_t^i ($\bar{C}_t^i$) denotes the time-t consumption (aggregate consumption) of type $i \in \{o, r\}$ household and parameter h_i governs the degree of habit formation in consumption. N_t^i is hours worked by household of type i. φ is the inverse of the Frisch elasticity of labour supply. σ is the inverse of the intertemporal elasticity of substitution.

The optimiser household maximises continuation value of utility subject to a sequence of budget constraints[18]:

$$\begin{aligned} P_t C_t^o + R_t^{-1} B_{t+1}^o + V_t^{eq} S_t^o = {} & (1-\tau_t) W_t N_t^o + P_t R_t^k K_t^o + (V_t^{eq} + P_t D_t^o) S_{t-1}^o \\ & + B_t^o - P_t T_t^o - P_t I_t^o - P_t ST^o, \end{aligned} \tag{A9}$$

where P_t is the aggregate price level, W_t is the nominal wage and N_t^o is hours worked by OPT. Thus, $W_t N_t^o$ is the labor income received by the optimiser household. R_t^k is the real rental rate on capital, K_t^o, in real terms and I_t^o is real investment, T_t^o are lump-sum taxes (or transfers, if negative) paid by the optimisers (hence, the superscript o). Thus, $R_t^k K_t^o$ is the after-tax income earned on capital. D_t^o are real dividends from ownership of firms. Further, B_{t+1}^o is the amount of risk-free bonds and R_t is the gross nominal interest rate. Following Gali et al. (2007) we assume, without loss of generality, that the steady-state lump sum taxes (ST^o) are chosen in a way that steady-state consumption of ROT and OPT households equal in steady-state. τ_t is the tax rate on labor income which also appears in the budget constraint of non-Ricardians:

$$P_t C_t^r = (1-\tau_t) W_t N_t^r + P_t ST^r.$$

There are two types of firms. Intermediary firms produce varieties and face Rotemberg type adjustment cost when setting their products' price. Perfectly competitive firms bundle intermediary goods into a single final good.

Intermediary firm z maximises profits (dividends) subject to quadratic price adjustment costs:

$$\max E_t \sum_{i=0}^{\infty} \beta^t \frac{\Psi_{t+i}(z)}{\Psi_t(z)} \left[D_{t+i} - \frac{\chi_P}{2} \left(\frac{P_{t+i}(z)}{\Pi P_{t+i-1}(z)} - 1 \right)^2 P_{t+i} Y_{t+i} \right], \tag{A10}$$

[17] Optimiser is also called Ricardian and rule-of-thumb as non-Ricardian due to the fact that the former is forward-looking but the latter is not.

[18] For the rest of the paper, a variable without a time subscript denotes steady-state value.

where $\beta^t \frac{\Psi_{t+i}(z)}{\Psi_t(z)}$ is the stochastic discount factor. The Rotemberg price-adjustment cost parameter, χ_P is set such that it is consistent with the duration of Calvo price rigidity in Rudebusch and Swanson (2012). Π is steady-state infation and is chosen to be one in our setup. $P_{t+i}D_{t+i}$ denotes the nominal value of aggregate dividends and is defined as:

$$P_{t+i}D_{t+i}(z) = P_{t+i}(z)Y_{t+i}(z) - W_{t+i}N_{t+i}(z) - P_{t+i}I_{t+i}(z),$$

where W_{t+i} denotes nominal wages.

The production function is given by:

$$Y_{t+i}(z) = A_{t+i}K^{\alpha}_{t+i}(z)N^{1-\alpha}_{t+i}(z).$$

The cost-minimisation problem of the competitive goods bundler firm for variety z can be written as:

$$Y_{t+i}(z) = \left(\frac{P_{t+i}(z)}{P_{t+1}}\right)^{-\varepsilon} Y_{t+i},$$

where ε is the elasticity of substitution between varieties.

Further, intermediaries face a cost, $\omega(I_{t+i}, K_{t+i-1})$, when adjusting capital stock which evolves as follows:

$$K_{t+i}(z) = (1-\delta)K_{t+i-1}(z) + \omega(I_{t+i}(z), K_{t+i-1}(z))K_{t+i-1}(z).$$

The functional form for capital adjustment costs is the following:

$$\omega(I_t(z), K_{t-1}(z)) = \frac{a_1}{1-\frac{1}{\chi^K}}\left(\frac{I_t}{K_{t-1}}\right)^{1-\frac{1}{\chi^K}} + a_2.$$

Parameter χ^K is the elasticity of investment-to-capital ratio with respect to Tobin's q. χ^K is also estimated by GMM. The parameters a_1 and a_2 are chosen such that capital adjustment costs are zero in the deterministic steady state such that $\frac{I}{K} = \delta$, $\omega(I,K) = \delta$, $\omega'(I,K) = 1$.

In the next section we describe monetary and fiscal rules. We start with the description of monetary policy.

MONETARY POLICY

The New Keynesian model is closed by an interest rate rule similar to the one in Rudebusch and Swanson (2012):

$$R_t = \rho_I R_{t-1} + (1-\rho_I)[R + \log\bar{\Pi}_t + g_\pi \log(\bar{\Pi}_t/\Pi^*) + g_y \log(Y_t/Y)] + \varepsilon^i_t, \tag{A11}$$

where R_t is the policy rate, $\bar{\Pi}_t$ is a four-quarter moving average of inflation, and Y is the steady-state level of output. Π^* is the target rate of inflation, and ε^i_t is an iid shock with mean zero and variance σ^2_i. ρ_I denotes interest rate smoothing. R is steady-state of the nominal interest rate. g_π and g_y measures strenght of the reaction of monetary policy to deviations of inflation and output from the target.

The four-quarter moving average of inflation ($\bar{\Pi}_t$) can be approximated by a geometric moving average of inflation:

$$\log\bar{\Pi}_t = \theta_\pi \log\bar{\Pi}_{t-1} + (1-\theta_\pi)\log\Pi_t, \tag{A12}$$

where $\theta_\pi = 0.7$ ensures that the geometric average in equation (A12) has an effective duration of approximately four quarters.

FISCAL POLICY

The government spending follows the process:

$$\log(G_t/G) = \rho_G \log(G_{t-1}/G) + \varepsilon^G_t, \;\; 0 < \rho_G < 1, \tag{A13}$$

where G is the steady-state level of G, and ε_t^G is an iid shock with mean zero and variance σ_G^2.

Here, the government can issue debt that is retired by labor income taxes:

$$b_t + \tau_t w_t N_t = \frac{R_{t-1}b_{t-1}}{\Pi_t} + g_t, \tag{A14}$$

where b_t and w_t represent real government debt and real wages, respectively. All quantities are expressed in real terms, except for the nominal interest rate (R_t). $R_{t-1}b_{t-1}$ denotes interest payments on the previous period's debt.

We consider two cases: i) fiscal budget is balanced in each period (still there is steady-state debt) ii) debt is time-varying. In both cases it is labor income tax revenue which is used to retire debt. In case i) one imposes the restriction $b_t = b_{t-1} = b$ for all t, then expression (A14) boils down to the balanced budget case.

In case ii) a fiscal rule is specified to allow for a reaction of the tax rate to changes in debt as well as output:

$$d\tau_t = \rho_\tau d\tau_{t-1} + \rho_{\tau b}\widehat{b}_{t-1} + \rho_{\tau y}\widehat{y}_{t-1} + \varepsilon_t^\tau. \tag{A15}$$

In equation (A15) variables are defined as: $d\tau_t \equiv \tau_t - \tau$, $\widehat{b}_t \equiv (b_t - b)/y$, and $\widehat{y}_t \equiv (y_t - y)/y$.

The specification of the fiscal rule in equation (A15) has four main features (see also Leeper et al. (2010) and Zubairy (2014)). First, parameter $\rho_{\tau y}$ captures how taxes respond to the deviations of output from its steady-state (this is the so-called 'automatic stabilizer' component of fiscal policy).

Second, parameter $\rho_{\tau b}$ indicates the response of income taxes rate to the state of government debt.

Third, the autoregressive terms, ρ_g and ρ_τ in equations (A13) and (A15), respectively, capture the persistent nature of government purchases and taxation.

Fourth, the tax shock ε_t^τ, which has a mean of zero and variance σ_τ^2 is meant to capture unforseen changes in the tax rate (uncertainty about fiscal policy).

AGGREGATION AND MARKET CLEARING

Finally, market clears for labor, capital and bonds. Further, the equilibrium is symmetric meaning that households and firms make identical decisions so that the index z can be eliminated. The shares in firms sum up to one and net bond-holdings are zero in equilibrium. Further details on derivations and a full list of equilibrium conditions can be found in the online appendix.

EQUITY PRICING

The holding period return (for the period between t and $t+1$) on equity is defined as

$$R_{t,t+1}^{eq} = \frac{V_{t+1}^{eq} + D_{t+1}}{V_t^{eq}\Pi_{t+1}}.$$

The literature usually concerns leveraged returns on equity (see e.g. Croce (2014)). In particular, the excess return on equity i.e. the difference between the return on equity and the return on the risk-free asset is multiplied by the levarage factor (ϕ_{lev}) and is also subject to dividend payout shocks (ϵ_t^d):

$$R_{ex,t}^{LEV} = \phi_{lev}(R_{t,t+1}^{eq} - R_{t,t+1}) + \epsilon_t^d. \tag{A16}$$

In equation (A16) the innovation of the cash-flow shock is standard normal with mean zero and variance σ_d^2 ($\epsilon_t^d \sim i.i.d.N(0,\sigma_d^2)$). The cash-flow shock, ϵ_t^d, only affects the volatility of excess returns but not the mean of the equity premium. The volatility of the cash-flow shock, σ_d is estimated by GMM joint with the other parameters of the model. Hence, the equity premium in Table (A1) is defined as $R_{ex,t}^{LEV}$.

BOND PRICING

Under no-arbitrage the Euler equation for nominal bonds can be written as:

$$B_{\tau,t} = E_t[M_{t+1}B_{\tau-1,t+1}], \tag{A17}$$

where $B_{\tau,t}$ is the price of a nominal bond of maturity τ, M is the stochastic discount factor which is defined as

$$M_{t+1} = \beta E_t\left\{\frac{\Psi_{t+1}}{\Psi_t}\frac{1}{\Pi_{t+1}}\right\},$$

where Ψ_t is the marginal utility of consumption at time t and Π_{t+1} is gross inflation at time $t+1$.

Therefore, bond prices with maturity ranging from $\tau = 1$ to $\tau = 40$ are constructed recursively using a chain of 40 Euler equations:

$$\begin{aligned} B_{1,t} &= E_t[M_{t+1}], \\ B_{2,t} &= E_t[M_{t+1}B_{1,t+1}], \\ B_{3,t} &= E_t[M_{t+1}B_{2,t+1}], \\ &\vdots \\ B_{40,t} &= E_t[M_{t+1}B_{39,t+1}], \end{aligned}$$

where we assumed that $B_{0,t+1} = 1$. In order to convert bond prices into yields let us take the log of equation (A17), denote the τ-period yield-to-maturity as $R_{\tau,t} = \log(1 + R_t^{net}) \equiv -\frac{1}{\tau}\log B_{\tau,t}$ and we arrive at:

$$R_{\tau,t} = E_t m_{t+1} - E_t\pi_{t+1} + R_{\tau-1,t}.$$

The nominal term premium is defined as the difference betwen the bond yield expected by a risk-averse Ricardian investor who has Epstein-Zin preferences and the yield risk-neutral Ricardian investor. The latter is consistent with rolling over one-period risk-free investment in line with the expectations hypothesis of the term structure).

Online Appendix D – A discussion of results from the extended model

THE ROLE OF EPSTEIN-ZIN PREFERENCES AND VARIOUS SHOCKS

We report the mean and standard deviation of the slope of the term structure as well as the excess holding period return, which are regarded as imperfect measures of the mean and standard deviations of the nominal term premium (see Table A1). Due to the inclusion of Epstein-Zin preferences in the utility of Ricardian households, the model is able to fit not only the mean and standard deviation of the equity premium but also the mean and standard deviation of the nominal term premium. The model features various shocks, such as technology, monetary policy and dividend payout shocks, which help the model fit the data better. In the extended model setup, temporary technology shocks help account for the high bond premium, which is a compensation mainly for inflation risks, as in Rudebusch and Swanson (2012). In the following subsections, we provide intuition on why capital adjustment costs contribute to explaining the equity premia and why price rigidity is helpful even in the extended model setup. Further, we explain why limited asset market participation is successful in accounting for the high equity premium as well as for the low variability of the risk-free rate.

THE ROLE OF CAPITAL ADJUSTMENT COSTS IN THE EXTENDED MODEL

In the absence of capital adjustment, cost consumption smoothing is easily achieved by changing production plans. Jermann (1998) introduces capital adjustment costs to reduce the ability of perfectly mobile capital in providing insurance.[19] It is also well known that the price of capital (Tobin's q) is constant in the absence of capital adjustment cost; hence, the return on capital does not change with the price of capital. We confirm the results of Croce (2014), who finds that in the absence of any investment (or capital) friction, i) the investment becomes too volatile and less correlated with consumption growth, ii) the equity premium falls due to the lack of movement in the price of capital and iii) the risk-free rate is too high.

The columns denoted with a * in Table A1 contain results from model simulations without capital adjustment costs. In the absence of capital adjustment costs, the standard deviation of output and consumption increases. This result is in line with the findings of Croce (2014). As the standard deviation of Ricardian consumption does not change significantly when capital adjustment costs are removed, the rise in the standard deviation of aggregate consumption is mainly driven by the higher variability in non-Ricardian consumption (the standard deviation of non-Ricardian consumption is not reported in the table). The nominal term premium halves without capital adjustment costs (a result that would not be present in the standard Ricardian-only model). Although the standard deviation of aggregate labor does not change, the aggregate wage is more volatile.

The absence of capital adjustment costs implies that capital can be changed at zero cost. As a result, firms change prices less frequently, and hence, the standard deviation of inflation drops. As the nominal interest rate mainly responds to changes in inflation via the Taylor rule, lower variability in inflation implies a less volatile short-term nominal interest rate. The investment also displays more variability in the absence of capital adjustment costs. The real interest rate varies less, while the 10-year nominal bond yield is somewhat more volatile without capital adjustment costs. Table A1 also shows that the model with capital adjustment cost overestimates while the model without adjustment cost underestimates the empirical Sharpe ratio (0.27).

THE ROLE OF PRICE RIGIDITY, THE CONDUCT OF MONETARY POLICY AND MONETARY POLICY SHOCKS IN THE EXTENDED MODEL

When prices are rigid, monetary policy shocks and the conduct of monetary policy matter for allocations in the economy. Specifically, rigid prices induce firms to react by changing production instead of adjusting prices in response to monetary and

[19] The model of Jermann (1998) does not feature Epstein-Zin preferences, so habit formation in consumption is necessary to make households concerned about the variability of the consumption path.

Table A1
Moments from the models

Unconditional Moment	US data, 1960-2007	T.-v. debt	T.-v. debt*	Const. debt	Const. debt*
SD(I)	5.6	6.82	8.38	6.07	8.12
SD(dC)	2.69	2.87	2.82	2.65	2.77
SD(L)	1.71	1.79	1.87	1.41	1.26
SD(W/P)	0.82	0.91	1.38	1.43	2.49
SD(π)	2.52	2.61	3.69	4.34	4.20
SD(R)	2.71	2.85	2.59	4.21	3.97
SD(R^{real})	2.30	2.34	2.41	1.26	1.36
SD ($R^{(40)}$)	2.41	2.61	3.43	3.47	3.73
Mean($NTP^{(40)}$)	1.06	0.87	1.26	1.32	1.13
SD($NTP^{(40)}$)	0.54	0.43	0.46	0.43	0.45
Mean($R^{(40)} - R$)	1.43	1.35	1.62	1.52	1.48
SD($R^{(40)} - R$)	1.33	1.37	1.34	1.54	1.52
Mean($x^{(40)}$)	1.76	1.83	2.65	2.64	2.71
SD($x^{(40)}$)	23.43	19.42	19.98	21.34	22.73
Mean(EQPR)	6.1	4.8	2.7	5.1	2.4
SD(EQPR)	22.23	12.52	15.39	13.33	16.62
Sharpe Ratio	0.27	0.38	0.18	0.37	0.14
Corr(dC, π)	-0.34	-0.26	-0.17	-0.21	-0.23
Corr($dC, dInve$)	0.39	0.21	-0.04	0.16	-0.07
Corr($dC, EQPR$)	0.25	0.16	-0.12	0.14	-0.13
Corr($d(\tau WL)/Y, dY$)	0.63	0.48	0.54	0.25	0.27
SD($d(\tau WL)/Y$)	3.06	3.57	3.74	0.83	0.92

*Notes: Mean, SD, Corr and Autocorr denote the unconditional mean, standard deviation, correlation and first-order autocorrelations. Const. and T.-v. stands for constant and time-varying, respectively. $NTP^{(40)}$=nominal term premium on a 40-quarter bond, $R^{(40)} - R$ is the slope and $x^{(40)}$ is the excess holding period return for a 10-year bond. Moments calculated using parameters estimated with GMM on US data for 1960-2007. EQPR denotes the equity premium. The Sharpe ratio defined as the mean of the equity premium divided by the standard deviation of equity. * indicates the version of the model without capital adjustment costs.*

technology shocks. With higher price rigidity, real variables such as consumption exhibit higher volatility. As consumption determines the stochastic discount factor, the return on equity will also be more volatile.

When the model is approximated at least to the second order, higher volatility of the stochastic discount factor strengthens the precautionary savings motive. This leads to a reduction in the risk-free rate, and thus, the risk-free rate puzzle is resolved (de Paoli et al. (2010)). As our extended model is approximated to the third order, monetary policy in this setup leads to a more volatile risk-free rate, and therefore, monetary policy shocks reduce precautionary savings. However, as we noted before, monetary policy shocks are not the main driver of business cycles and risk premia in the extended model, and their effect on the risk-free rate is limited.

The strength of the response of monetary policy to changes in inflation captured by the interest rate rule also matters. In particular, a higher reaction to inflation in the monetary policy rule reduces the variability of inflation. It also diminishes, relatively, the role of output-gap stabilization, leading to a more volatile stochastic discount factor and a higher equity risk premium. In contrast, a higher reaction to inflation reduces the inflation risk-premium component of the nominal term premium. Hence, we conclude that the extended model is successful in solving the bond and equity premium puzzles jointly.

Online Appendix E – Data description

The macroeconomic and financial time series used in either the VAR and/or GMM estimation are the following:
PY: Gross Domestic Product. Bureau of Economic Analysis (BEA). Nipa Table 1.1.5, line 1.
P: GDP deflator personal consumption expenditures. Source: BEA, Nipa Table 1.1.4, line 2.
I: Gross private domestic investment. Source: BEA. Nipa Table 1.1.5, line 7.
C: Private Consumption. Source: BEA, Nipa Table 1.1.6, line 2.
N: hours, measure of the labour input. This is computed as $N = H(1 - U/100)$, where H and U are the average over monthly series of hours and unemployment. Source: BLS, series LNU02033120 for hours and LNS14000000 for unemployment.
R: Federal Funds rate from the online database of the Federal Reserve Bank of St. Louis.
G: Government consumption is computed as current consumption expenditures (line 21)+gross government investment (line 42)+net purchases of non-produced assets (line 44)-consumption of fixed capital (line 45). Source: BEA, Nipa Table 3.2
W_t: Wage and Salary Disbursement. BEA. Series ID A576RC1.
$W_t N_t$: labour income tax base. Source: Nipa Table 1.12 (line 3).
τ_t: average effective labour income tax rate as in Jones (2002) and Leeper et al. (2010). We follow the procedure in the appendix of Leeper et al. (2010) to construct τ_t.
B/Y: government-debt-to-GDP ratio. St. Louis Fed Database.
EQPR: equity premium. Log return data is calculated on the basis of close-bid stock prices available from the website of Robert Shiller.
NTP: nominal term premium. Data from the website of Tobias Adrian, see also Adrian et al. (2013) who used this data.
*M*2: M2 Money Stock in billions of dollars from the database of the Federal Reserve Bank of St. Louis.
U: Unemployment rate for aged 15-64: All Persons for the United States from LNS14000000 for unemployment from the BLS database.

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