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:

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

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

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

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

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

Let us define

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

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

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

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

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

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

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

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:

$$\begin{aligned} ep_t &= -cov_t(sdf_{t,t+1}, rr_{i,t+1}) \\ &= -cov_t(-A_c A_y \xi_{t+1}, \kappa_1 A_{z1}\xi_{t+1} + \kappa_{d\xi}A_y\xi_{t+1}) \\ &= \underbrace{A_c A_y\{\kappa_1 A_{z1} + k_{d\xi}A_y\}}_{\text{price of risk}} \times \underbrace{\sigma_\xi^2}_{\text{amount of risk}}, \end{aligned}$$

where the second row used equations (4), (5) and (6) and ignored constants and time-t terms, which would be irrelevant because we are looking at 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

[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.

to a sequence of budget constraints[18]:

$$P_tC_t^o + R_t^{-1}B_{t+1}^o + V_t^{eq}S_t^o = (1-\tau_t)W_tN_t^o + P_tR_t^kK_t^o + (V_t^{eq} + P_tD_t^o)S_{t-1}^o + B_t^o - P_tT_t^o - P_tI_t^o - P_tST^o, \tag{A9}$$

where P_t is the aggregate price level, W_t is the nominal wage and N_t^o is hours worked by OPT. Thus, $W_tN_t^o$ 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, $R_t^kK_t^o$ 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:

$$P_tC_t^r = (1-\tau_t)W_tN_t^r + P_tST^r.$$

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:

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

[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):

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

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_t^i is an iid shock with mean zero and variance σ_i^2. 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:

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

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:

$$\log(G_t / G) = \rho_G \log(G_{t-1} / G) + \varepsilon_t^G, \quad 0 < \rho_G < 1, \quad \text{(A13)}$$

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 $b_t = b_{t-1} = 0$ for all t, then expression (A14) boils down to the balanced budget case ($G_t = \tau_t w_t N_t$ for all t in the absence of steady-state debt $b = 0$).

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:

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

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

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

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.

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

[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.

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 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.

$M2$: 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.