Portfolio Rebalancing Channel and the Effects of Large-Scale Stock and Bond Purchases*

Sami Alpanda†
University of Central Florida

Serdar Kabaca‡
Bank of Canada

August 9, 2024

Abstract

We quantify the effects of large-scale stock purchases by a central bank, and compare these to bond purchases, using an estimated dynamic stochastic general equilibrium macro-finance model with nominal and real rigidities and portfolio rebalancing effects. The latter arise from imperfect substitutability between stocks and short- and long-term government bonds in mutual funds' portfolios. Since households' consumption-savings decisions are tied to expected portfolio returns, the required return on all three assets affect overall demand in the economy. The model shows that the central bank's equity purchases would lower the risk and term premiums on stocks and long-term bonds, respectively, and thereby stimulate economic activity. Since stocks comprise a larger share in asset portfolios and are less substitutable with short-term securities relative to long-term bonds, the effects of stock purchases on aggregate demand are larger than similar-sized bond purchases.

Keywords: Portfolio rebalancing effects, large-scale stock purchases, quantitative easing, institutional asset demand, DSGE.

JEL Classification: E52, E44, E32.

*We thank co-editor Kenneth D. West, two anonymous referees, Simon Gilchrist, Refet Gurkaynak, Filippo Occhino and seminar participants at the International Conference of the Turkish Economic Association 2022, Western Economic Association International Annual Conference 2023, Computational Economics and Finance Conference 2023, Symposium of the Society of Nonlinear Dynamics and Econometrics 2023, and International Conference on Economic Modeling and Data Science (EcoMod2024) for suggestions and comments. We also thank Callum Goulet-Kilgour for excellent research assistance. All remaining errors are our own. The views expressed in this paper are those of the authors. No responsibility should be attributed to the Bank of Canada.

†University of Central Florida, Department of Economics, College of Business, 4336 Scorpius Street, Orlando, FL 32816. Phone: (407) 823-1575, e-mail: sami.alpanda@ucf.edu.

‡Bank of Canada, Canadian Economic Analysis Department, 234 Wellington Street, Ottawa, Ontario K1A 0G9, Canada. Phone: (613) 782-7509, e-mail: skabaca@bankofcanada.ca.

1 Introduction

Following the financial crisis of 2008 and the coronavirus crisis of 2020, the Federal Reserve (Fed) cut its short-term policy rate to the zero-lower bound (ZLB), and conducted unconventional policies such as forward guidance and large-scale asset purchases (LSAPs) in order to lower long-term interest rates and thereby stimulate the economy.[1] These types of polices were employed by other central banks as well, including the European Central Bank and the Bank of Japan (BoJ). LSAPs, also known as *quantitative easing* (QE) policies, typically involved central banks purchasing long-term government bonds and mortgage-backed securities (MBS), in exchange for increasing the supply of the monetary base, in particular bank reserves. Between 2008-2014, the Fed increased its holdings Treasuries by about 2 trillion dollars in several stages, while also purchasing close to 1.7 trillion dollars of agency MBS and other government sponsored enterprise (GSE) backed debt. This amounted increasing the monetary base from close to 6% of nominal GDP in the pre-crisis period to about 22% by 2014 (see Figure 1). The Fed let some of its holdings of long-term debt securities expire between 2014-2019, but following the coronavirus crisis of 2000, it purchased an additional 3.5 trillion dollars of Treasuries and 1.2 trillion dollars of agency debt, while the monetary base increased to more than 30% of nominal GDP.[2]

The BoJ was unique among advanced economy central banks for purchasing corporate equity as part of its QE policy beginning December 2010.[3] This policy was extended during the BoJ's "Quantitative and Qualitative Easing" (QQE) initiative in 2013, and since then, the bank accumulated more than 37 trillion yen worth of stocks by the end of 2023 (equivalent to about 6% of Japanese nominal GDP and 4% of the total market capitalization of Japanese corporations), mainly through purchases of Exchange Traded Funds (ETFs) that track the TOPIX (Tokyo Stock Price Index) and the Nikkei 225 and Nikkei 400 indexes. The Fed has not engaged in large-scale purchases of corporate equity as part of its QE policy, partly because this would have required a change to the Federal Reserve Act by Congress. Nevertheless, several policymakers and economists have supported the idea that the Fed be allowed to purchase a wider set of securities as part of its QE operations,

[1] Debortoli et al. (2020) find that the performance of the U.S. economy was not materially affected by the presence of a binding ZLB constraint between 2009-2015 (i.e., "ZLB irrelevance hypothesis"), supporting the efficacy of these unconventional policies in supporting the economy at the ZLB.

[2] QE1 was announced in November 2008 with an initial plan to purchase $600 billion of MBS and agency debt, although the plan was later extended in March 2009 to also purchase $300 billion of Treasuries and an additional $850 billion of MBS and agency debt (Bhattarai and Neely, 2006). QE2 was announced in November 2010 and involved the Fed purchasing $600B of long-term Treasuries, which was worth about 4% of nominal GDP at the time. Our stock purchase exercise in Section 4 is designed to be equivalent to the size of the QE2 episode. In September 2011, the Fed announced that "it will sell $400B of short-term Treasuries and use the proceeds to buy $400B of long-term Treasuries" and later in December 2012, it announced that "it will purchase $45B of longer-term Treasuries per month for the indefinite future" (Swanson, 2021), where these LSAPS were dubbed as Operation Twist and QE3, respectively. Following the coronavirus crisis, in March 2020, the Fed announced "purchases of at least $500 billion in Treasuries and $200 billion in agency mortgage-backed securities totaling 3.3 percent of 2020 GDP" (Occhino, forthcoming).

[3] Note that the Swiss National Bank has purchased foreign stocks in the past as part of its foreign exchange rate policy. Also, the Hong Kong Monetary Authority has bought domestically-listed stocks as part of its response to the Asian Financial Crisis in 1998 (Harada and Okimoto, 2021).

including risk assets such as corporate stocks and bonds.[4] Following the coronavirus crisis, the Fed did end up purchasing some corporate *bond* ETFs, but this was very limited in terms of its quantity and scope.

Large-scale purchases of long-term risk assets, especially stocks, could potentially have a large effect on financial values and the real economy. First, long-term risk assets are likely less substitutable with base money and similar short-term risk-free instruments, relative to long-term government bonds and MBS, in the portfolios of commercial and investment banks and non-bank financial institutions. Thus, a large-scale purchase of stocks by a central bank could potentially cause significant portfolio rebalancing effects in private sector portfolios. This premise is by-and-large supported by the recent finance literature on "Demand System Asset Pricing" (c.f. Koijen and Yogo, 2019), which finds that institutional demand for stocks is fairly inelastic, implying that a sustained regime of stock purchases by a central bank would have a large impact on asset prices. Second and relatedly, LSAPs in long-term risk assets would lead to a decline in the risk premiums, as well as a decline in the term premium, in interest rates and discount factors relevant for different components of aggregate demand. This is also by-and-large consistent with the empirical literature investigating the BoJ's stock ETF purchases (c.f., Barbon and Gianinazzi, 2019).[5]

Our goal in this paper is to, first, construct a theoretical framework that can be used to analyze the effects of large-scale stock purchases by a central bank, and second, to *quantify* the potential effects of these purchases in the U.S. context and compare their effects to similar-sized bond purchases. To these ends, we build a dynamic stochastic general equilibrium (DSGE) macro-finance model with standard nominal and real rigidities, but augment it with portfolio rebalancing effects. The latter effects arise from imperfect substitutability between stocks and short- and long-term government bonds in the mutual funds' portfolios based on their asset diversification motive. Thus, the relative holdings of these assets in private asset portfolios now matter for the risk premium on stocks as well as the term premium on long-term bonds. Furthermore, these changes have a material impact on aggregate demand. In particular, households' discounting is tied to the expected return on the whole asset portfolio, rather than only short-term bonds as in the standard setup. Therefore, the required return on all three assets affect overall aggregate demand, commensurate with their portfolio shares. The central bank is thus able to stimulate the economy through large-scale stock or long-term bond purchases, even when the short-term interest rate is constrained at the ZLB.[6]

[4]See, for example, the speech on March 6, 2020 of Eric Rosengren, then President of the Federal Reserve Bank of Boston, titled "Observations on Monetary Policy and the Zero Lower Bound". A similar issue had emerged in the late 1990s, when it seemed like the Treasury may be able to retire all of its outstanding debt if the projected budget surpluses materialized. This would have forced the Fed to come up with alternative securities to purchase as part of its usual open market operations to alter the federal funds rate or make a special agreement with the Treasury to continue issuing debt securities (Broaddus and Goodfriend, 2001).

[5]We discuss these literatures in more detail in the *Related literature* subsection of the Introduction.

[6]Note that QE may also operate through a signaling channel whereby the duration of QE purchases is interpreted by markets as a form of *forward guidance* on the short-term policy rate's duration at the ZLB (Christensen and Rudebusch, 2012). In our model, we abstract from this signaling channel and focus only on the portfolio rebalancing effects of QE operations. Nevertheless, we do assume in our experiments that the Fed keeps the short-term rate at the ZLB for 4 quarters when conducting QE.

We estimate our DSGE model using Bayesian likelihood methods and U.S. data between 1960-2023. To capture the effects of the ZLB constraint on the policy rate and the effects of forward guidance and QE announcements during the crisis episodes, we include news shocks to monetary policy and bond supply processes, and identify the former using Overnight Indexed Swap (OIS) rates in the estimation. We find that purchasing 2.65% of the outstanding equity (equivalent to 4% of steady-state output) for a duration of 5 years would lower the required return on stocks by about 100 basis points (bps), increase stock prices by 1.5%, and stimulate output in the order of 0.46%.[7] The effects of equity purchases on aggregate demand are also found to be larger than similar-sized long-term bond purchases. In particular, a similar sized purchase of long term bonds result in 0.31% peak impact on output. This is because long-term bonds comprise a smaller share in asset portfolios, and are more substitutable with short-term bonds, relative to stocks. In general, our results suggest that the Fed's QE operations may become more potent if it involves purchases of corporate stocks along with purchases of government bonds and MBS. Sensitivity analysis on our results indicates that the effects of equity purchases would increase with the duration of the ZLB constraint on the policy rate or with the share of stocks in mutual funds' portfolios, and decrease with higher elasticities of substitution between stocks and bonds or between short- and long-term bonds.

1.1 Related literature

Our model focuses on the portfolio rebalancing channel of QE operations, which has been studied extensively in the recent DSGE literature, but only for large-scale *bond* purchases and not for *stock* purchases. The idea for the portfolio rebalancing effect dates at least back to Tobin and Brainard (1963), Brainard and Tobin (1968), and Tobin (1969). According to this idea, the required return on assets adjust when their relative supply changes, since these assets are not perfectly substitutable in agents' portfolios. In particular, when the relative supply of an asset increases, agents require a higher return to hold the additional supply as they are forced to rebalance their portfolios. Conversely, when the relative supply of an asset decreases, (e.g., due to a large-scale purchase by the central bank), the asset's required return declines. This would not be the case in a frictionless macro-finance framework, where the relative supply of assets only have a negligible effect on required returns, even if one considered higher-order terms of the model.[8] With the portfolio rebalancing channel studied here, we generate return spreads even under a first-order approximation of the model, abstracting from the model's higher-order terms. In particular, relative

[7] As noted before, QE2 involved the Fed announcing in November 2010 that it was going to purchase $600 billion in long-term U.S. Treasuries, an amount close to 4% of annual US GDP at the time. We thus scale the size of the QE shock in our model simulations to an amount equal to 4% of the steady-state level of (annual) output.

[8] In a standard consumption-CAPM (capital asset pricing model) framework, changes in risk and term premiums are determined based on the covariance of asset returns with the households' stochastic discount factor, where the latter is a function of consumption growth. With a first-order approximation of the model, certainty equivalence is imposed and covariance terms are ignored; hence, the spreads between asset returns are reduced to zero. Spreads become non-zero under higher-order approximations of the model, but nevertheless, changing the relative supply of assets have negligible effects on expected returns and asset prices in the absence of other frictions.

asset holdings of financial intermediaries (i.e., "mutual funds" in the model) and shocks to their portfolio preferences provide endogenous and exogenous variation, respectively, in risk and term premiums.

As noted above, there are by now many papers in the literature that incorporate the portfolio rebalancing channel within DSGE models. Andres et al. (2004) was the first to incorporate Tobin and Brainard's ideas into a DSGE model, to investigate the effects of monetary policy shocks through its effects on the yield curve. Chen et al. (2012) and Priftis and Vogel (2016) use a similar framework to study the effects of large-scale bond purchases in a closed-economy context for the U.S. and the Euro Area, respectively. Alpanda and Kabaca (2020) and Kolasa and Wesolowski (2020) extend this framework to an open economy set-up to analyze the effects of large-scale bond purchases on the originating country as well as the spillover effects of the policy on other countries. Erceg et al. (2024) use a similar model to compare the domestic and international effects of quantitative easing versus quantitative tightening policies. Valchev (2020) uses a small-open economy set-up with imperfect substitutability between domestic and foreign short-term bonds to show that the portfolio rebalancing effect helps resolve the interest rate parity puzzle. Benes et al. (2013a) also utilizes the portfolio rebalancing channel in an open economy model to investigate the effects of central banks' sterilized foreign exchange interventions. Vitek (2014) uses a 40-country DSGE model with financial frictions including the portfolio rebalancing channel to investigate the spillover effects of monetary and fiscal policies from the domestic economy to others.[9] Our paper contributes to this literature by investigating and quantifying the effects of large-scale stock purchases within an estimated closed-economy DSGE macro-finance framework with a portfolio rebalancing channel, where the latter arises from the inelastic asset demand of financial institutions.

Frankel (1985) present some early empirical evidence on the portfolio rebalancing channel related to stocks. Scholes (1972), Shleifer (1986), and Greenwood (2005) exploit natural experiments involving the redefinition of various stock market indexes that have triggered portfolio rebalancing by institutional investors, and show that the short-term demand curve for stocks is downward-sloping. There are also several empirical papers that analyze the effects of the BoJ's ETF purchases. Barbon and Gianinazzi (2019) document that the Bank's ETF purchases had "a positive, sizeable and persistent impact on stock prices, suggesting that demand curves for stocks are downward-sloping in the long-run" and they estimate "an elasticity close to one since each yen invested translates into an increase in total market valuation of roughly one yen". Harada and Okimoto (2021) use a difference-in-difference methodology to examine the effects of the BoJ's purchasing of Nikkei 225 ETFs, and find a cumulative treatment effect on the Nikkei 225 of around 20%, while Kawamoto et al. (2023) estimate the policy's effect on the level of GDP between 0.9% and 1.3%. Similarly, Charoenwong et al. (2021), Adachi et al. (2021), and Cohen (2023) find that the BoJ's ETF purchases significantly lifted stock prices, but they lead to different conclusions regarding the effect of

[9] This paper features a portfolio rebalancing channel for stocks and bonds within an assets-in-utility setup, but assumes that the elasticity of substitution between short- and long-term bonds is equivalent to that between bonds and stocks, and does not consider the effects of large-scale equity purchases by central banks.

the policy on corporate capital investment.

As mentioned before, there is also a related and burgeoning literature in empirical finance on asset demand systems of households and financial institutions and their implications for asset pricing (e.g., Koijen and Yogo, 2019; Gabaix and Koijen, 2021; Gabaix et al., 2023; and Koijen et al., forthcoming). Estimates from this literature indicate that financial institutions have fairly inelastic asset demand functions, mainly due to the presence of investment mandates of these institutional investors. As a result, flow of funds between financial assets (including those that would be caused by QE policies of central banks) are expected to have a large impact on asset prices. For example, Koijen and Yogo (2019) estimate that "the price impact of a 10 percent aggregate demand shock for the median stock was 26 percent in 2017:2", implying an asset price multiplier of 2.6.[10] Note that our estimated general equilibrium framework, featuring all the standard bells-and-whistles of medium-scale business cycle models as well as an inelastic asset demand system derived from imperfect asset substitutability between stocks and bonds, implies a smaller price multiplier on stocks, close to 0.6, but note that we are only considering a *temporary* stock purchase by the central bank. Our estimate is also closer to the elasticity estimate of around 1 in Barbon and Gianinazzi (2019), which, as noted above, consider the stock ETF purchases of the BoJ in an empirical framework.

The portfolio rebalancing channel is also discussed in various empirical studies as an important channel through which large-scale *bond* purchases have lowered long-term yields (e.g., Krishnamurthy and Vissing-Jorgensen, 2011; Baumeister and Benati, 2013; D'Amico et al., 2012; Gagnon et al., 2011; Rogers et al., 2014; Hamilton and Wu, 2012; Doh, 2010; and Bernanke, 2012). Chung et al. (2012), Engen et al. (2015), and Gambacorta et al. (2014) argue that large-scale bond purchases have strengthened economic activity through the decline in long-term interest rates as well as the increase in equity values following these measures. Bhattarai and Neely (2016) provide a comprehensive survey of the empirical literature on the effects of U.S. unconventional monetary policies including large-scale bond purchases, and report that these policies have significantly improved macroeconomic outcomes, raising U.S. output and inflation. They also note that the portfolio balance channel appears to be an important conduit of unconventional policy.

Our paper also provides an alternative interpretation for the "risk shocks" in Smets and Wouters (2007; "SW" hereafter), which has become the workhorse DSGE model for analyzing business cycles. In SW, risk-premium shocks mechanically drive a wedge between the risk-free rate and the risky rate relevant for consumption and investment demand, and thereby generate co-movement in these two series.[11] Fisher (2015) interprets this shock as unexpected changes in the liquidity benefits arising from government bond holdings, such as their use in repo markets. As noted above, in our paper, relative asset holdings of financial intermediaries (i.e., mutual funds) and shocks to their portfolio preferences provide endogenous and exogenous variation, respectively, in the "risk wedge" of SW. The endogenous variation in this wedge arises from the diversification motive of investors which

[10] Gabaix and Koijen (2021) estimate an even larger multiplier, in the order of 5.

[11] SW identify risk shocks in their estimation only through non-financial variables. Christiano et al. (2014) and Gilchrist et al. (2009) identify these shocks using data on risk premiums on corporate bonds, while Alpanda (2013) identifies them using equity return data.

leads to inelastic asset demand and portfolio rebalancing effects, while the exogenous variation in the wedge captures shocks to the portfolio preferences of investors which prompts them to alternate between "search-for-yield" and "flight-to-safety" type behavior in their demand for holding equity in firms versus holding short- and long-term government bonds. These changes then directly affect both the consumption and investment demand expressions similar to SW, as well as impacting the asset pricing expressions through the risk and term premia components similar to Jondeau and Rockinger (2019).[12]

The remainder of the paper proceeds as follows. The next section introduces the model. Section 3 discusses the estimation of model parameters. Section 4 reports the main results from the model including those for the large-scale stock and bond purchase experiments, Section 5 conducts sensitivity analysis on these results, and Section 6 concludes.

2 Model

In this section, we build a closed-economy DSGE model with real and nominal rigidities, and portfolio rebalancing effects. The model economy is populated by households, financial intermediaries ("mutual funds"), intermediate-goods producers, labor and final-goods aggregators, as well as monetary and fiscal policy rules. In what follows, we describe the optimization problems of each type of agent and the resulting equilibrium conditions.

Households' and mutual funds' problems are key to the results in the paper. In particular, the households' Euler condition shows that the expected return on the asset portfolio as a whole, rather than just the expected return on short-term bonds, is the relevant interest rate that affects aggregate demand. Furthermore, the mutual funds' diversification motive between stocks and short- and long-term bonds ensure that the relative asset holdings in private asset portfolios affect the term and risk premia on long-term bonds and stocks, and therefore the required return on the asset portfolio. Thus, QE-type policies of the central bank through large-scale stock or bond purchases can affect both the required return on asset portfolios and aggregate demand, even when the short-term interest rate is constrained at the ZLB.

2.1 Households

Preferences The economy is populated by a unit measure of infinitely-lived households indexed by i, whose intertemporal preferences over consumption, $c_t(i)$, and labor supply, $n_t(i)$, are described by the following expected utility function:

$$E_t \sum_{\tau=t}^{\infty} \beta^{\tau-t} \upsilon_t \left(\frac{\left(c_\tau(i) - \zeta c_{\tau-1}\right)^{1-\sigma}}{1-\sigma} - A_t^{1-\sigma} \frac{n_\tau(i)^{1+\vartheta}}{1+\vartheta} \right), \tag{1}$$

[12] Jondeau and Rockinger (2019) feature portfolio adjustment costs to generate risk shocks in their model, but these shocks only affect asset prices, and not the demand expressions for consumption and investment goods. Similarly, Amano and Shukayev (2012) features risk shocks that drive a wedge between the risk-free rate and the return on capital, but their risk shocks only affect investment demand directly, but not consumption demand.

where t indexes time, $\beta < 1$ is the time-discount parameter, ζ is the external habit parameter for consumption, σ is the inverse of the elasticity of intertemporal substitution, and ϑ is the inverse of the Frisch-elasticity of labor supply. A_t denotes the trend level of productivity, which grows with a constant factor of γ (i.e., $A_t = \gamma^t$).[13] Finally, the time preference shock, υ_t, follows an exogenous AR(1) process:

$$\log \upsilon_t = \rho_\upsilon \log \upsilon_{t-1} + \varepsilon_{\upsilon,t}, \tag{2}$$

where ρ_υ is the persistence parameter and $\varepsilon_{\upsilon,t}$ denote the *i.i.d.* innovations.[14]

Labor demand curve facing households The labor services supplied by each household is heterogeneous; these are aggregated into a homogeneous labor service by perfectly-competitive labor intermediaries, who in turn rent these labor services to intermediate-goods producers. The labor intermediaries use a standard Dixit-Stiglitz aggregator as

$$n_t = \left[\int_0^1 n_t(i)^{\frac{\eta_{n,t}-1}{\eta_{n,t}}} di\right]^{\frac{\eta_{n,t}}{\eta_{n,t}-1}}, \tag{3}$$

where $\eta_{n,t}$ is the elasticity of substitution between the differentiated labor services. Consequently, the labor demand curve facing household i is given by

$$n_t(i) = \left(\frac{W_t(i)}{W_t}\right)^{-\eta_{n,t}} n_t, \tag{4}$$

where W_t and n_t denote the aggregate nominal wage rate and labor supply, respectively. To capture cost-push shocks on wages, we specify an exogenous AR(1) process on $\theta_{w,t} = \eta_{n,t}/(\eta_{n,t} - 1)$ as:

$$\log \theta_{w,t} = (1 - \rho_w) \log \theta_w + \rho_w \log \theta_{w,t-1} + \varepsilon_{w,t}, \tag{5}$$

where θ_w refers to the gross mark-up of real wage over the household's marginal rate of substitution (MRS) between labor and consumption at the steady state.

Budget constraint The households' period budget constraint is given by

$$c_t(i) + a_t(i) \leq \frac{W_t(i)}{P_t} n_t(i) + r_t^a a_{t-1}(i) - tax_t + tr_t - \frac{\kappa_w}{2}\left(\frac{W_t(i)/W_{t-1}(i)}{\gamma \pi_{t-1}^{\varsigma_w} \pi^{1-\varsigma_w}} - 1\right)^2 \frac{W_t}{P_t} n_t, \tag{6}$$

where a_t denotes real household savings held at the mutual fund, r_t^a refers to the real realized (state-contingent) return on the asset portfolio, P_t is the aggregate price level, tax_t refers to real lump-sum taxes paid to the government, and tr_t refers to all lump-sum transfers received by households.

[13] This is added to the utility specification to make it compatible with balanced growth. Thus, the disutility from labor does not become negligible as consumption grows over time.

[14] In what follows, we denote the persistence and standard deviation of all shocks as ρ and σ, respectively, with appropriate subscripts corresponding to each shock.

The last term on the right-hand side is a quadratic cost of wage adjustment, where κ_w is a level parameter, $\pi_t = P_t P_{t-1}$ is the aggregate inflation factor, π is the steady-state value of inflation, and ς_w determines indexation of wage adjustments to past inflation.

Optimality conditions The households' objective is to maximize their utility subject to the budget constraint in (6), labor demand curve for labor in (4), and appropriate No-Ponzi conditions. The first-order conditions with respect to consumption and savings are respectively given by (after imposing a symmetric equilibrium)

$$\upsilon_t \left(c_t - \zeta c_{t-1}\right)^{-\sigma} = \lambda_t, \tag{7}$$

$$1 = E_t\left[\left(\beta \frac{\lambda_{t+1}}{\lambda_t}\right) r^a_{t+1}\right], \tag{8}$$

where λ_t denotes the Lagrange multiplier on the budget constraint and captures the marginal utility of consumption. After detrending and log-linearization, these expressions can be combined to get

$$\widehat{c}_t = \frac{\zeta/\gamma}{1+\zeta/\gamma}\widehat{c}_{t-1} + \frac{1}{1+\zeta/\gamma}E_t\widehat{c}_{t+1} - \frac{1-\zeta/\gamma}{\left(1+\zeta/\gamma\right)\sigma}\left[E_t\widehat{r}^a_{t+1} - \left(1-\rho_\upsilon\right)\widehat{\upsilon}_t\right], \tag{9}$$

which links consumption demand to changes in the expected returns on the asset portfolio held at mutual funds, $E_t\widehat{r}^a_{t+1}$.[15] As we show later in the discussion of mutual funds, this expected return on the asset portfolio is determined as a weighted average of the expected returns on the short- and long-term bonds as well as stocks.

The rest of the households' optimality conditions are standard. In particular, the conditions for optimal labor and wage-setting can be combined to derive a New-Keynesian wage Phillips curve, which, after detrending and log-linearization, can be written as

$$\widehat{\pi}_{w,t} - \varsigma_w\widehat{\pi}_{t-1} = \widetilde{\beta}\left(E_t\widehat{\pi}_{w,t+1} - \varsigma_w\widehat{\pi}_t\right) + \frac{\eta_n - 1}{\kappa_w}\left[\vartheta\widehat{n}_t + \frac{1}{1-\zeta/\gamma}\left(\widehat{c}_t - \frac{\zeta}{\gamma}\widehat{c}_{t-1}\right) - \widehat{w}_t + \widehat{\theta}_{w,t}\right], \tag{10}$$

where $\widetilde{\beta} = \beta\gamma^{1-\sigma}$ and the nominal wage inflation, $\widehat{\pi}_{w,t}$, and the real wage rate, $\widehat{w}_t$, are related as

$$\widehat{\pi}_{w,t} - \widehat{\pi}_t = \widehat{w}_t - \widehat{w}_{t-1}. \tag{11}$$

According to the wage Phillips curve, there is a wedge between the real wage and households' MRS, and wage stickiness and wage mark-up shocks provide endogenous and exogenous variation in this "labor wedge", with a long-run correction to the steady-state wage markup given by $\theta_w = \eta_n/(\eta_n - 1)$.

[15] To detrend the model, we divide growing variables by γ^t, except for capital stock, k_t, which is divided by γ^{t+1} for convenience, and for marginal utility, λ_t, which is multiplied by $\gamma^{\sigma t}$.

2.2 Mutual funds

We follow Harrison (2011) to separate the households' consumption-saving problem from their asset allocation problem within savings using financial intermediaries.[16] In particular, there is a unit measure of perfectly-competitive mutual funds in the economy, which allocate the financial savings of households into firm stocks as well as short- and long-term government bonds, and distribute the related portfolio returns from these assets back to households.

Asset returns and mutual fund cash flow Mutual funds enter period t owning s_{t-1} shares in firms, $b_{S,t-1}$ short-term government bonds, and $b_{L,t-1}$ long-term government bonds from the last period. During period t, they receive payments from these asset holdings, manage net cash flows with households, and make portfolio allocations for period t subject to transactions costs. The net real cash outflow from mutual funds to households in period t is $r_t^a a_{t-1} - a_t$, which is equal to

$$\left(\frac{V_t + D_t}{P_t}\right) s_{t-1} + \frac{P_{t-1}}{P_t} b_{S,t-1} + \left(\frac{P_{t-1} + \frac{\kappa}{\pi_t} Q_{L,t}}{P_t}\right) b_{L,t-1} - (1+\psi)\left(\frac{V_t}{P_t} s_t + \frac{Q_{S,t}}{P_t} b_{S,t} + \frac{Q_{L,t}}{P_t} b_{L,t}\right) + \Phi_t, \tag{12}$$

where V_t denotes the nominal *ex-dividend* share price, D_t is the per-share dividend payments of firms, and $Q_{S,t}$ and $Q_{L,t}$ denote the nominal *ex-coupon* prices of short- and long-term bonds issued in period t, respectively. ψ is the mutual funds' cost of maintaining its asset portfolio, while Φ_t denotes the benefits that arise from diversification as we explain in further detail in the next subsection.

Short-term bonds are discount bonds which mature in one period. In particular, a short-term bond issued in period $t-1$ pays a pre-determined nominal face value of P_{t-1} during period t. Long-term bonds are modeled as perpetuities with decaying nominal coupon payments. In particular, a long-term bond issued in period $t-1$ pays pre-determined nominal coupon payments of P_{t-1}, κP_{t-1}, $\kappa^2 P_{t-1}$,... in periods t, $t+1$, $t+2$,...., where $\kappa < 1$ is the coupon decay parameter. With this specification, short-term bonds are simply long-term bonds with $\kappa = 0$. Furthermore, arbitrage implies that the *ex-coupon* price of a long-term bond issued in period $t-1$ is equal to κ/π_t times the value of a long-term bond issued in period t, $Q_{L,t}$. This allows us to write long-term bonds in recursive form in the cash-flow equation above, without having to keep track of the issue dates for each cohort of bonds (Woodford, 2001).

Transaction costs and diversification motive The mutual fund incurs a proportional cost of ψ on its asset holdings, but also benefits from keeping these in relative proportions. This portfolio diversification motive is captured by the function $\Phi_t = \Phi_1 \Phi\left(., b\left(.,.\right)\right)$, which combines the mutual funds' stock and bond holdings in a nested CES (constant elasticity of substitution) fashion. In

[16] As we show in the Online Appendix, we can instead capture the portfolio allocation problem within the households' problem directly, and the results would be equivalent. We follow the separation here for expositional convenience.

particular, the bond subportfolio holdings, b_t, is defined as

$$b_t = \left[\gamma_{b,t}^{\frac{1}{\lambda_b}} \left(\frac{Q_{S,t} b_{S,t}}{P_t} \right)^{\frac{\lambda_b - 1}{\lambda_b}} + (1 - \gamma_{b,t})^{\frac{1}{\lambda_b}} \left(\frac{Q_{L,t} b_{L,t}}{P_t} \right)^{\frac{\lambda_b - 1}{\lambda_b}} \right]^{\frac{\lambda_b}{\lambda_b - 1}}, \tag{13}$$

where $\gamma_{b,t}$ determines the share of short-term bonds in the bond subportfolio, and λ_b is the elasticity of substitution between short- and long-term bonds. Similarly, the total asset portfolio is specified as

$$\Phi_t = \Phi_1 \left[\gamma_{a,t}^{\frac{1}{\lambda_a}} b_t^{\frac{\lambda_a - 1}{\lambda_a}} + (1 - \gamma_{a,t})^{\frac{1}{\lambda_a}} \left(\frac{V_t s_t}{P_t} \right)^{\frac{\lambda_a - 1}{\lambda_a}} \right]^{\frac{\lambda_a}{\lambda_a - 1}}, \tag{14}$$

where Φ_1 is a scale parameter, $\gamma_{a,t}$ determines the share of bonds in the portfolio, and λ_a is the elasticity of substitution between stocks and bonds.[17]

The time variation in $\gamma_{a,t}$ and $\gamma_{b,t}$ are assumed to be exogenous and both follow AR(1) processes as

$$\log \gamma_{a,t} = (1 - \rho_a) \log \gamma_a + \rho_a \log \gamma_{a,t-1} + \varepsilon_{a,t}, \tag{15}$$

$$\log \gamma_{b,t} = (1 - \rho_b) \log \gamma_b + \rho_b \log \gamma_{b,t-1} + \varepsilon_{b,t}, \tag{16}$$

where γ_a and γ_b denote the corresponding portfolio shares at the steady state. As we show later, these portfolio shocks will be important in determining the term premium on long-term bonds and the risk premium on stocks.

Optimality conditions The mutual funds' objective is to maximize the present value of cash outflows to households, where they discount the future using the stochastic discount factor of households, $\beta \lambda_{t+1} / \lambda_t$. The resulting first-order conditions with respect to short-term bonds, long-term bonds, and stocks are respectively given by

$$(1 + \psi)\, q_{S,t} = E_t \left[\left(\beta \frac{\lambda_{t+1}}{\lambda_t} \right) \frac{1}{\pi_{t+1}} \right] + \frac{\partial \Phi_t}{\partial b_t} \frac{\partial b_t}{\partial b_{S,t}}, \tag{17}$$

$$(1 + \psi)\, q_{L,t} = E_t \left[\left(\beta \frac{\lambda_{t+1}}{\lambda_t} \right) \left(\frac{1 + \kappa q_{L,t+1}}{\pi_{t+1}} \right) \right] + \frac{\partial \Phi_t}{\partial b_t} \frac{\partial b_t}{\partial b_{L,t}}, \tag{18}$$

$$(1 + \psi)\, v_t = E_t \left[\left(\beta \frac{\lambda_{t+1}}{\lambda_t} \right) (v_{t+1} + d_{t+1}) \right] + \frac{\partial \Phi_t}{\partial s_t}, \tag{19}$$

where $q_{S,t} = Q_{S,t}/P_t$, $q_{L,t} = Q_{L,t}/P_t$, $v_t = V_t/P_t$, and $d_t = D_t/P_t$, denote the real counterparts of the short-term bond price, long-term bond price, stock price, and dividends.

[17] Note that we set $\Phi_1 = \psi$ in our calibration to ensure that the portfolio costs and diversification benefits cancel each other out at the steady state of the model.

Note that the gross nominal yields on short- and long-term bonds are related to bond prices as[18]

$$I_t = \frac{1}{q_{S,t}} \text{ and } I_{L,t} = \frac{1}{q_{L,t}} + \kappa, \tag{20}$$

while the real realized gross returns from the three assets in period t are respectively given by

$$r_t = \frac{I_{t-1}}{\pi_t}, \; r_{L,t} = \frac{I_{L,t}}{\pi_t}\frac{q_{L,t}}{q_{L,t-1}}, \text{ and } r_t^s = \frac{v_t + d_t}{v_{t-1}}. \tag{21}$$

After detrending and log-linearization, we can use the expressions above, along with the households' Euler condition, to show that the return on the asset portfolio is simply the weighted average of the returns on the three assets, with the weights given by the corresponding portfolio weights:

$$\widehat{r}_t^a = \gamma_a \gamma_b \widehat{r}_t + \gamma_a (1-\gamma_b) \widehat{r}_{L,t} + (1-\gamma_a) \widehat{r}_t^s. \tag{22}$$

As noted before, in this model, the interest rate relevant for consumption and investment decisions is the expected return on the whole asset portfolio, $E_t \widehat{r}_{t+1}^a$, rather than the expected return on short-term bonds only, $E_t \widehat{r}_{t+1} = \widehat{I}_t - E_t \widehat{\pi}_{t+1}$. Thus, in order to stimulate the economy, (unconventional) monetary policy can try to lower the expected return on long-term bonds and stocks, $E_t \widehat{r}_{L,t+1}$ and $E_t \widehat{r}_{t+1}^s$, even when the short-term interest rate is constrained at the zero lower bound (ZLB).

Term and risk premia The mutual funds' first-order conditions with respect to short- and long-term bonds imply that the term premium is tied to the relative holdings in the bond subportfolio as

$$E_t \widehat{r}_{L,t+1} = E_t \widehat{r}_{t+1} + \frac{\psi}{\lambda_b}\left(\widehat{q}_{L,t} + \widehat{b}_{L,t} - \widehat{q}_{S,t} - \widehat{b}_{S,t} + \frac{1}{1-\gamma_b}\widehat{\gamma}_{b,t}\right). \tag{23}$$

Large-scale bond purchases by the central bank can thus lead to a reduction in the term premium, since the QE policy would lower the net supply of long-term bonds outstanding relative to short-term bonds, $\widehat{q}_{L,t} + \widehat{b}_{L,t} - \widehat{q}_{S,t} - \widehat{b}_{S,t}$. Also note that a positive innovation in the bond portfolio shock, $\widehat{\gamma}_{b,t}$, is associated with an increase in the term premium, as agents are incentivized to reallocate their bond subportfolios towards short-term bonds and away from long-term bonds.

Similarly, the mutual funds' optimality conditions imply that the risk premium on stocks over the bond subportfolio is tied to the relative holdings of stocks and bonds as

$$E_t \widehat{r}_{t+1}^s = E_t \widehat{r}_{t+1}^b + \frac{\psi}{\lambda_a}\left(\widehat{v}_t + \widehat{s}_t - \widehat{b}_t + \frac{1}{1-\gamma_a}\widehat{\gamma}_{a,t}\right), \tag{24}$$

where $\widehat{b}_t = \gamma_b \left(\widehat{q}_{S,t} + \widehat{b}_{S,t}\right) + (1-\gamma_b)\left(\widehat{q}_{L,t} + \widehat{b}_{L,t}\right)$, and $E_t \widehat{r}_{t+1}^b$ denotes the expected return on the

[18] The yield on the long-term bond, $I_{L,t}$, is the interest rate that equates the price of the bond with the present value of its cash flow. Thus, $Q_{L,t} = \frac{P_t}{I_{L,t}} + \frac{\kappa P_t}{I_{L,t}^2} + \frac{\kappa^2 P_t}{I_{L,t}^3} + ...$, which implies the yield expression in the main text.

bond subportfolio given by

$$E_t\widehat{r}^b_{t+1} = \gamma_b E_t\widehat{r}_{t+1} + (1-\gamma_b)\, E_t\widehat{r}_{L,t+1}. \tag{25}$$

Thus, the central bank's large-scale equity purchases can reduce the risk premium on stocks by lowering the value of stocks in private portfolios relative to bonds, $\widehat{v}_t + \widehat{s}_t - \widehat{b}_t$. Furthermore, a positive innovation in the portfolio shock, $\widehat{\gamma}_{a,t}$, is associated with an increase in the risk premium as agents reallocate their portfolios towards stocks and away from bonds.

The expressions in (22), (23), and (24) can be combined to relate the expected return on the asset portfolio, $E_t\widehat{r}^a_{t+1}$, to the ex-ante real short-term rate, $\widehat{I}_t - E_t\widehat{\pi}_{t+1}$, as

$$\begin{aligned} E_t\widehat{r}^a_{t+1} &= \widehat{I}_t - E_t\widehat{\pi}_{t+1} + \frac{\psi(1-\gamma_b)}{\lambda_b}\left(\widehat{q}_{L,t} + \widehat{b}_{L,t} - \widehat{q}_{S,t} - \widehat{b}_{S,t}\right) \\ &\quad + \frac{\psi(1-\gamma_a)}{\lambda_a}\left(\widehat{v}_t + \widehat{s}_t - \widehat{b}_t\right) + \frac{\psi}{\lambda_a}\widehat{\gamma}_{a,t} + \frac{\psi}{\lambda_b}\widehat{\gamma}_{b,t}. \end{aligned} \tag{26}$$

Note that in the absence of the diversification motive, all three assets would be perfectly substitutable (i.e., $\lambda_a = \lambda_b = \infty$), which implies that the expected returns on all assets would be equal to a first-order approximation (i.e., $E_t\widehat{r}^s_{t+1} = E_t\widehat{r}_{L,t+1} = E_t\widehat{r}_{t+1}$). Thus, as in standard DSGE models, the interest rate relevant in making consumption and investment decisions would simply be equal to the short-term interest rate (set by the central bank) minus expected inflation (i.e., $E_t\widehat{r}^a_{t+1} = \widehat{I}_t - E_t\widehat{\pi}_{t+1}$). The presence of the diversification motive here breaks the equivalence between the required returns on the three assets even under a first-order approximation of the model, and ties changes in relative asset holdings of agents to the risk and term premia on stocks and long-term bonds, and thereby aggregate demand. Portfolio shocks $\gamma_{a,t}$ and $\gamma_{b,t}$ provide further exogenous variation in these premia.[19]

Finally, note that one can relate the short- and long-term bond yields as

$$\widehat{I}_{L,t} = \frac{\kappa}{I_L}E_t\widehat{I}_{L,t+1} + \left(1-\frac{\kappa}{I_L}\right)\left[\widehat{I}_t + \frac{\psi}{\lambda_b}\left(\widehat{q}_{L,t} + \widehat{b}_{L,t} - \widehat{q}_{S,t} - \widehat{b}_{S,t} + \frac{1}{1-\gamma_b}\widehat{\gamma}_{b,t}\right)\right], \tag{27}$$

which can be iterated forward to get

$$\widehat{I}_{L,t} = \left(1-\frac{\kappa}{I_L}\right)E_t\sum_{h=0}^{\infty}\left(\frac{\kappa}{I_L}\right)^h\left[\widehat{I}_{t+h} + \frac{\psi}{\lambda_b}\left(\widehat{q}_{L,t+h} + \widehat{b}_{L,t+h} - \widehat{q}_{S,t+h} - \widehat{b}_{S,t+h} + \frac{1}{1-\gamma_b}\widehat{\gamma}_{b,t+h}\right)\right]. \tag{28}$$

The above term-structure expression shows that the long-term yield is equal to the sum of present and future expected short-term interest rates, similar to the expectations hypothesis, plus a premium that depends on the present and future relative bond holdings in the mutual funds' bond subportfolio.

[19] In the canonical model in SW, a wedge does exist between the risk-free rate set by the central bank and the risky rate relevant for consumption and investment demand as in here, but this "risk premium" wedge is assumed to be fully exogenous.

2.3 Intermediate goods producers

The production side of the model is relatively standard, except that firms own the capital stock (rather than renting them from households) and they make dividend payments to their shareholders (i.e., mutual funds).

Production and capital accumulation There is a unit measure of monopolistically-competitive intermediate goods producers indexed by $j \in [0,1]$, which combine their capital holdings with labor services hired from households to produce intermediate goods. The output of firm j is described by the following Cobb-Douglas production function:

$$y_t(j) = z_t \left[u_t(j)\, k_{t-1}(j)\right]^{\alpha} \left[A_t n_t(j)\right]^{1-\alpha} - A_t f, \tag{29}$$

where u_t is the capital utilization rate, k_{t-1} is the firm's capital stock brought from the previous period, α is the share of capital, z_t is the total factor productivity (TFP) shock following an AR(1) process, and f denotes the fixed cost of production, which is scaled by the trend level of productivity, $A_t = \gamma^t$, to ensure that it does not become negligible as the economy grows over time.

Firms accumulate capital according to the following law-of-motion

$$k_t = (1-\delta)\, k_{t-1} + \left[1 - \frac{\kappa_x}{2}\left(\frac{x_t}{\gamma x_{t-1}} - 1\right)^2\right] z_{x,t} x_t, \tag{30}$$

where δ is the depreciation rate, and $z_{x,t}$ denotes shocks to investment-specific technological change following an AR(1) process. Note that there are quadratic adjustment costs related to the contribution of new investment, x_t, to installed capital, k_t, with κ_x denoting the level parameter for these costs.

Goods demand curve facing firms The output supplied by each firm is heterogeneous. As is standard, we assume that these are aggregated into a homogeneous output good by perfectly-competitive final goods producers, who in turn sell these final goods to households (as consumption goods), to intermediate goods firms (as investment goods), or to the government (as government expenditure goods). The aggregation is standard, and results in a demand curve for each firm-specific output good as

$$y_t(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\eta_{y,t}} y_t, \tag{31}$$

where $P_t(j)$ is the goods price for the firm-specific good, y_t is aggregate output, and $\eta_{y,t}$ refers to the elasticity of substitution between the intermediate goods in the aggregation function. To capture cost-push shocks on prices, we specify an exogenous AR(1) process on $\theta_{p,t} = \eta_{y,t}/(\eta_{y,t} - 1)$ as:

$$\log \theta_{p,t} = (1-\rho_p) \log \theta_p + \rho_p \log \theta_{p,t-1} + \varepsilon_{p,t}, \tag{32}$$

where θ_p refers to the gross mark-up of prices over the marginal cost of production at the steady-state.

Dividend payments The intermediate goods firm's dividend payments to mutual funds in period t is given by

$$\frac{D_t(j)}{P_t} = \frac{P_t(j)}{P_t} y_t(j) - \frac{W_t}{P_t} n_t(j) - x_t(j) - \frac{\kappa_u}{1+\varpi}\left(u_t(j)^{1+\varpi} - 1\right) k_{t-1}(j) - \frac{\kappa_p}{2}\left(\frac{P_t(j)/P_{t-1}(j)}{\pi_{t-1}^{\varsigma_p}\pi^{1-\varsigma_p}} - 1\right)^2 y_t, \tag{33}$$

where the last two terms denote the costs related to capital utilization and price adjustment, respectively. In particular, κ_u and ϖ are the level and elasticity parameters for the utilization cost specification, while κ_p denotes the level parameter for the price-adjustment costs, and ς_p controls the degree to which adjustments in prices are indexed to past inflation.[20]

Optimality conditions Intermediate firms maximize the present value of their dividends (using the mutual funds', and therefore the households', stochastic discount factor) subject to their production function in (29), law-of-motion for capital in (30), and the firm-specific goods demand of final goods producers in (31).

The first-order-condition of the intermediate goods firms with respect to capital is (after imposing a symmetric equilibrium):

$$q_t = E_t\left[\left(\beta\frac{\lambda_{t+1}}{\lambda_t}\right)[(1-\delta)q_{t+1} + r_{k,t+1}]\right], \tag{34}$$

where $r_{k,t}$ is the *shadow* rental rate of capital, and q_t is the Lagrange multiplier with respect to the law-of-motion for capital, which captures the relative price of installed capital in terms of output goods. After detrending and log-linearization, and combining with the stochastic discount factor of mutual funds, the expression above can be written as

$$\widehat{q}_t = \frac{\widetilde{\beta}(1-\delta)}{\gamma} E_t\widehat{q}_{t+1} + \left(1 - \frac{\widetilde{\beta}(1-\delta)}{\gamma}\right) E_t\widehat{r}_{k,t+1} - E_t\widehat{r}^a_{t+1}, \tag{35}$$

which shows that the relative price of installed capital, q_t, is affected by the required return on the asset portfolio, $E_t\widehat{r}^a_{t+1}$. This is indeed how the model will generate investment demand effects from changes in portfolio returns, since investment demand relates to q_t. In particular, the first-order condition with respect to investment goods yields an investment demand expression relating

[20] As is standard, κ_u is set to ensure that the capital utilization rate, u_t, is, without loss of generality, equal to 1 at the steady-state.

investment to Tobin's marginal q, which, after detrending and log-linearization, can be written as[21]

$$\widehat{x}_t - \widehat{x}_{t-1} = \widetilde{\beta}\left(E_t \widehat{x}_{t+1} - \widehat{x}_t\right) + \frac{1}{\kappa_x}\left(\widehat{q}_t + \widehat{z}_{x,t}\right). \tag{36}$$

Thus, decreases in expected portfolio returns will not only stimulate consumption demand, but also lead to an increase in Tobin's q, thereby incentivizing investment demand as well and helping generate co-movement in the consumption and investment series similar to SW.

The rest of the optimality conditions of the firm are standard. In particular, the *shadow* rental rate on capital above is given by

$$r_{k,t} = \Omega_t \alpha \frac{y_t + \gamma^t f}{k_{t-1}} - \frac{\kappa_u}{1+\varpi}\left(u_t^{1+\varpi} - 1\right), \tag{37}$$

where Ω_t denotes the Lagrange multiplier with respect to the production function, capturing the firm's real marginal cost of production. Similarly, the optimality conditions for the capital utilization rate and labor demand are given respectively by

$$\Omega_t \alpha \frac{y_t + \gamma^t f}{u_t} = \kappa_u u_t^{\varpi} k_{t-1}, \tag{38}$$

$$\Omega_t \left(1-\alpha\right) \frac{y_t + \gamma^t f}{n_t} = w_t. \tag{39}$$

Finally, the intermediate goods firm's pricing decision gives rise to the following Phillips curve expression (after imposing a symmetric equilibrium):

$$\widehat{\pi}_t - \varsigma_p \widehat{\pi}_{t-1} = \widetilde{\beta}\left(E_t \widehat{\pi}_{t+1} - \varsigma_p \widehat{\pi}_t\right) + \frac{\eta_y - 1}{\kappa_p}\left(\widehat{\Omega}_t + \widehat{\theta}_{p,t}\right). \tag{40}$$

Thus, price stickiness and mark-up shocks provide endogenous and exogenous variation, respectively, in the markup between prices and the marginal cost of production, with a long-run correction to the steady-state price markup given by $\theta_p = \eta_y/(\eta_y - 1)$.

2.4 Monetary policy and news shocks

The central bank targets the nominal short-term interest rate using a Taylor rule subject to the ZLB:

$$\log I_t = \max\left\{0, \rho \log I_{t-1} + (1-\rho)\left(\log I + a_\pi \log \frac{\pi_t}{\pi} + a_y \log \frac{y_t}{A_t y} + a_{\Delta y} \log \frac{y_t}{\gamma y_{t-1}}\right) + \widetilde{\varepsilon}_{I,t}\right\}, \tag{41}$$

where I and y are the steady-state values of the policy rate and detrended output level, respectively. The parameter ρ determines the extent of interest rate smoothing in the Taylor rule, while a_π, a_y,

[21] Note that the model counterpart of Tobin's marginal q is given by $q_t z_{x,t}$, which is the price of installed capital, q_t, relative to its replacement cost, $1/z_{x,t}$.

and $a_{\Delta y}$ determine the long-run responses of the interest rate to inflation, output gap, and output growth, respectively.

Since monetary policymaking often involves creating expectations regarding future changes to the policy rate, such as during the *forward guidance* episodes following the financial crisis, we let the exogenous part of the Taylor rule, $\widetilde{\varepsilon}_{I,t}$, include pre-announced deviations from the past (i.e., news shocks) as well as current innovations to the Taylor rule. In particular, we follow Del Negro et al. (2017) and let

$$\widetilde{\varepsilon}_{I,t} = \rho_I \widetilde{\varepsilon}_{I,t-1} + \varepsilon_{I,t} + \sum_{h=1}^{8} \varepsilon^h_{I,t-h}, \text{ with } \varepsilon^h_{I,t} \tilde{\ } NID\left(0, \sigma^2_{I,h}\right) \text{ for } h = 1, 2, ..., 8, \tag{42}$$

where $\varepsilon_{I,t}$ denotes the contemporaneous *i.i.d.* innovation in the monetary policy shocks and $\varepsilon^h_{I,t}$ are news shocks that are realized in period t but affect the exogenous part of the monetary policy rule in $t + h$.[22]

2.5 Fiscal policy

Similar to Chen (2012), we do not model the balance sheet or cash-flows of the central bank separately. Since the net cash flow of the central bank would ultimately accrue to the fiscal authority, we can consider the consolidated budget constraint of the government, which conceptually includes both fiscal and monetary authorities' flow constraints. This expression is given by

$$g_t + \frac{P_{t-1}}{P_t}\left(b_{S,t-1} + b_{L,t-1}\right) + \frac{V_t}{P_t}\left(s^{CB}_t - s^{CB}_{t-1}\right) = tax_t + \frac{Q_{S,t}}{P_t} b_{S,t} + \frac{Q_{L,t}}{P_t}\left(b_{L,t} - \frac{\kappa}{\pi_t} b_{L,t-1}\right) + \frac{D_t}{P_t} s^{CB}_{t-1}, \tag{43}$$

where g_t denotes real government expenditures and s^{CB}_t denotes the stock holdings of the central bank.[23] We assume that central bank's equity holdings is 0 at the steady state, and treat it as an exogenous variable in our stock purchase experiments in Section 4. For our estimation in the next section using U.S. data, we assume $s^{CB}_t = 0$ for all t.

Note that the bonds in the expression above refer to the bond holdings of mutual funds, and are thus conceptually net of the bond holdings of the central bank. Thus, we are going to capture a QE policy of the central bank purchasing long-term government bonds through a reduction in the long-term bonds outstanding in the expression above. Given the consolidated government budget

[22] With news shocks on monetary policy, the use of OIS data in the estimation will discipline the expectations of the agents. In particular, during the ZLB episodes in the post-2008 period, agents will not expect the interest rate to go below zero even if the standard Taylor rule would imply a negative rate. This is arguably a simpler alternative to the endogenous ZLB literature (e.g., Fernández-Villaverde, Gordon, Guerrón-Quintana, and Rubio-Ramírez, 2015) in terms of handling the non-linearity posed by the ZLB constraint in the estimation of the model.

[23] The expression above implicitly treats the monetary base created by the central bank and the short-term bonds issued by the fiscal authority as perfectly substitutable. This is a reasonable assumption, since monetary base and short-term bonds are close to perfect substitutes when short-term interest rates are at the ZLB or when the central bank pays interest on bank reserves. The data counterpart for short-term bonds in this model would thus include, not only the value of short-term government bonds outstanding (i.e., total supplied by the government minus held by the central bank), but also the monetary base liabilities of the central bank.

constraint above in (43), a reduction in the supply of long-term bonds outstanding would lead to an increase in short-term bonds outstanding, all else equal. Similarly, we will assume that the central bank's equity purchases also result in an equivalent increase in short-term bonds outstanding, which is akin to an increase in the monetary base that would result from the central bank's asset purchase in the real world.

Lump-sum taxes adjust with the level of government debt to rule out a Ponzi scheme for the government:

$$\frac{tax_t}{A_t y} = \Xi \left(\frac{y_t}{A_t y}\right)^{\tau_y} \left(\frac{q_{S,t-1} b_{S,t-1} + q_{L,t-1} b_{L,t-1}}{A_{t-1} b}\right)^{\tau_b}, \tag{44}$$

where Ξ is a level parameter that captures the steady-state level of taxes relative to output, and τ_y and τ_b determine the long-run responses of taxes to output and government debt, respectively.[24]

Finally, we assume that, in normal times, the government issues new long-term and short-term bonds to ensure that the relative value of bonds outstanding is

$$\frac{Q_{L,t} b_{L,t}}{Q_{S,t} b_{S,t}} = \Gamma_t, \tag{45}$$

where Γ_t is an exogenous process given by

$$\log \Gamma_t = (1 - \rho_\Gamma) \log \Gamma + \rho_\Gamma \log \Gamma_{t-1} + \varepsilon_{\Gamma,t} + \sum_{h=1}^{8} \varepsilon_{\Gamma,t-h}^{h}, \tag{46}$$

where $\varepsilon_{\Gamma,t}$ is the contemporaneous innovation, while $\varepsilon_{\Gamma,t}^{h}$ are news shocks, modeled similar to the news shocks on the monetary policy rate. We include these to the bond supply process to capture the effects of pre-announced changes in relative bond supply, such as the QE episodes in the post-2008 period.

In our simulations in Section 4, we capture large-scale bond purchases by the central bank through a negative shock to Γ_t. In the large-scale equity purchase simulation, we will disregard the proportional bond supply rule, and instead assume that equity purchases are financed solely by an increase in short-term bonds (akin to an increase in the monetary base). Thus, equity purchases will reduce the term premium on long-term bonds as well as the risk premium on stocks.[25]

2.6 Market clearing conditions

The final goods, y_t, can be used as consumption, investment, or government expenditure goods:[26]

$$c_t + x_t + g_t = y_t. \tag{47}$$

[24] Stability requires that the government cannot run a Ponzi scheme, and hence they need to correct taxes with respect to their debt level to ensure a balanced budget in the long run.

[25] As we show in Section 4, the results are qualitatively similar, but quantitatively weaker, when equity purchases are financed partly by long-term bonds as well.

[26] Note that we are implicitly assuming that all adjustment costs are accruing to households in lump-sum fashion (tr_t in equation 6), and therefore they do not enter the goods feasibility condition.

The stock market clearing is given by

$$s_t + s_t^{CB} = s_t^{out} = 1, \tag{48}$$

assuming, without loss of generality, that the total quantity of firm shares outstanding, s_t^{out}, is constant and equal to 1.[27]

The model's equilibrium is defined as prices and allocations such that households maximize the discounted present value of utility, and all firms and mutual funds maximize the discounted present value of cash-flows and dividends, subject to their constraints, and all markets clear.

3 Parameterization

We calibrate the parameters that primarily determine the steady state of the model, while estimating the remaining parameters that mainly affect model dynamics using U.S. data and Bayesian likelihood methods (An and Schorfheide, 2007; Fernández-Villaverde, 2010). In this section, we discuss the calibration of parameters that primarily determine the steady state, the posterior estimates obtained from the estimation of the remaining parameters, as well as the data used in the estimation.

3.1 Calibrated parameters

A list of the calibrated parameter values is given in Table 1, and the resulting steady state ratios are summarized in Table 2. To construct the portfolio shares, we use the Financial Accounts of the U.S. issued by the Federal Reserve. In particular, we consider the market value of equity issued by non-financial corporations (Table B.103) as well as the short- and long-term government bonds issued by the Federal government minus the corresponding holdings of the Federal Reserve (Table L.210). For the short-term bond series, we also add the monetary base (i.e., bank reserves and vault cash plus currency liabilities of the Federal Reserve in Table L.109). The portfolio share parameters at the steady state, γ_a and γ_b, are thus set to 0.33 and 0.42, respectively, based on the sample average for 1960Q1-2023Q4 of the constructed portfolio share series described above.

The steady state growth factor, γ, and the trend inflation factor, π, are both set to 1.005, corresponding to 2% real growth and annual inflation along the balanced growth path. We calibrate the capital share parameter in production, α, to 0.33 to match a two-thirds labor share in total income, while the depreciation rate of capital, δ, is set to 0.025, to match a target investment-output ratio of 18% and a capital-output ratio of 6 (i.e., 1.5 in annualized terms). The latter was picked based on the capital-to-value added ratio for the U.S. corporate sector, and is slightly lower than the

[27] Note that exogenous changes in the quantity of shares outstanding (s_t^{out}) through stock issuance, stock buybacks, or stock splits is neutral with respect to the real side of the economy in this set-up. Changes in s_t^{out} would result in a proportional change in the stock price V_t; thus $V_t s_t^{out}$ would stay the same and there would be no effect on the risk premium or any real variables. This is not true however when the total quantity of firm shares issued stays the same (i.e., $s_t^{out} = 1$), while a portion of these stocks are acquired by the central bank reducing the shares held by private agents (i.e., $s_t < 1$), as we consider in our large-scale stock purchase experiment in Section 4.

capital-output ratio for the whole U.S. economy. The steady state expressions for the capital share in income and the shadow rental rate of capital can then be combined to get $\alpha/(k/y) = \gamma/\widetilde{\beta} - 1 + \delta$, where the growth-adjusted time discounting is given by $\widetilde{\beta} = \beta\gamma^{1-\sigma}$. We use this expression and the above mentioned figures to calibrate the adjusted time-discount parameter, $\widetilde{\beta}$, to 0.976.

The portfolio cost parameter, ψ, is set to 0.02, reflecting the near 2% fees charged by asset managers in the real world.[28] The decay parameter for coupon payments of long-term bonds, κ, is calibrated to 0.975 implying a duration of 40 quarters for the bonds. The utilization cost level parameter, κ_u, is calibrated to imply, without loss of generality, a unit utilization rate at the steady state. The elasticity parameters for the labor and goods aggregators, η_n and η_y, are set to 11, implying that the net markups in prices and wages at the steady state, θ_p and θ_w, are 10%. Finally, the steady-state government expenditure level is set to ensure that its share in output, g/y, is 20%, and the tax level parameter, Ξ, is set to ensure that the consolidated government's budget constraint is satisfied, given the bond ratios and interest rates at the steady state.

3.2 Data

The model includes 8-period news shocks on monetary policy and bond supply processes, as well as 11 other shocks; namely, shocks to consumption, υ_t, investment, $z_{x,t}$, government expenditure, g_t, productivity, z_t, price, $\theta_{p,t}$, wage, $\theta_{w,t}$, risk premium, $\gamma_{a,t}$, term premium, $\gamma_{b,t}$, monetary policy, $\varepsilon_{I,t}$, relative bond supply, $\varepsilon_{\Gamma,t}$, and large-scale stock purchases, s_t^{CB}. Since stock purchases were not operational during the estimation period, we impose $s_t^{CB} = 0$ for all t.

We help identify the news shocks on bond supply by assuming that they have the same variance as the contemporaneous innovation in bond supply (i.e., $\sigma^2_{\Gamma,h} = \sigma^2_{\Gamma}$ for all $h = 1, ..., 8$). To identify the monetary policy news shocks, we include 3 to 24 month OIS rates to capture interest rate expectations (i.e., $E_t I_{t+h}$ for $h = 1, ..., 8$) in the estimation for the available period of 2002Q1-2023Q4.[29] We treat these series as missing observations for the pre-2002 period in the estimation, but note that we still have partial identification for this earlier period given our use of the long-term interest rate in the estimation.

To identify the remaining shock processes and the non-calibrated structural parameters, we use 10 macroeconomic and financial quarterly data series for the period 1960Q1 to 2023Q4 as observables.[30] These observables used in the estimation are output growth (Δy_t), consumption growth (Δc_t), investment growth (Δx_t), labor growth (Δn_t), real wage growth (Δw_t), inflation rate (π_t), short-term interest rate (I_t), long-term interest rate ($I_{L,t}$), real realized return on stocks

[28] Note that ψ cannot be identified separately from the portfolio elasticity parameters, λ_a and λ_b, in the risk and term premium equations; we thus calibrate ψ and estimate the latter.

[29] Lloyd (2021) finds that OIS rates "provide broadly reliable measures of rate expectations out to around the 2-year tenor".

[30] Given the challenges to estimating medium-scale DSGE models without a Covid-specific shock (Ferroni et al., 2022 and Del Negro et al., 2024), we also estimated our model excluding the Covid period using an end date of 2019Q4. Nevertheless, our parameter estimates, and therefore our main results, are not significantly affected by this change. These results are included in the Online Appendix.

(r_t^s), and the relative supply of bonds ($q_{L,t} + b_{L,t} - q_{S,t} - b_{S,t}$). All series are demeaned prior to estimation.[31]

Nominal GDP, its expenditure components, and labor income data were obtained from the National Income and Product Accounts (NIPA) of the Bureau of Economic Analysis (BEA). These were all deflated using the GDP deflator and divided by civilian non-institutional population, the latter obtained from the FRED database of the Federal Reserve Bank of St. Louis. For labor hours, we use the index series *Nonfarm Business Sector: Hours of All Persons*, constructed by the Bureau of Labor Statistics (BLS), and divide it by population. Similarly, for real wages, we use the index series *Nonfarm Business Sector: Real Compensation per Hour*, of the BLS. The inflation rate refers to GDP deflator inflation, the short-term interest rate is the Federal Funds rate, and the long-term interest rate is the yield on 10-year constant maturity Treasury securities. These interest rates were obtained from the FRED database, while the OIS rates are from Bloomberg, and all were converted from monthly to quarterly series by averaging.

The series for equity returns was constructed using data from the Financial Accounts of the U.S. published by the Federal Reserve Board. In particular, we use the market value of equity issued by non-financial corporations (Table B.103) as well as their dividend payments (Table L.103), where the latter includes stock buybacks of corporations (i.e., we subtract net stocks issued from dividends).[32] The series for the relative bond supply was also constructed using data from the Financial Accounts, as described in the previous subsection.

3.3 Prior distributions and posterior estimates

Tables 3 and 4 report the prior distributions used for the estimated structural and shock parameters, along with their corresponding estimates for the posterior mode, posterior mean, and the 90% Highest Posterior Density (HPD) interval.[33]

Prior distributions For the structural parameters with a unit support (i.e., the habit parameter, ζ, the indexation parameters, ς_p and ς_w, and the Taylor rule smoothing parameter, ρ), we use beta priors with mean 0.5 and standard deviation 0.15. For the structural parameters with positive support (but not necessarily constrained within the unit interval), we use gamma priors. In particular, the parameters for the portfolio elasticities, λ_a and λ_b, the (inverse) labor supply elasticity, ϑ, and the (inverse) elasticity of intertemporal substitution, σ, have gamma priors with mean 2 and standard deviation 0.5, while the investment adjustment cost parameter, κ_x, has a gamma prior with

[31] The beginning of the sample, 1960, was picked based on the data availability for the long-term bond yield in the FRED database. We demean the 2002-2023 OIS data by subtracting the 1960-2023 average of the short-term interest rate series, I_t.

[32] The resulting equity return series is very similar to that reported in SBBI (Stocks, Bonds, Bills, and Inflation) Yearbook (Ibbotson and Harrington, 2021), which only includes S&P500 stocks.

[33] We conduct the estimation using the Matlab routines in *Dynare* v6.0 (Adjemian et al., 2011). For the Metropolis-Hastings algorithm, we used a single chain of 1,000,000 draws with a 50% initial burn-in phase, and the acceptance rate was around 31%. We monitor and confirm convergence using trace plots and the chi-square convergence diagnostic test of Geweke (1999).

mean 5 and standard deviation 1.5. We rescale the price and wage adjustment cost parameters as $\kappa_p^{est} = \kappa_p/100$ and $\kappa_w^{est} = \kappa_w/100$, and use gamma priors with mean 2 and standard deviation 0.25 for these. Similarly, we use gamma priors with mean 1 and standard deviation 0.15 for the output and debt response parameters in the tax rule, τ_y and τ_b, and for the utilization cost parameter, ϖ.

For the Taylor rule response coefficient on inflation, a_π, we use a gamma prior with mean 1.5 and standard deviation of 0.15, while the output gap and output growth response coefficients, a_y and $a_{\Delta y}$, have gamma priors with mean 0.5 and standard deviation 0.15. Finally, for the shock persistence parameters, we use beta priors with 0.5 mean and 0.15 standard deviation, while for shock standard deviations, we use inverse-gamma priors with 0.5% mean and infinite variance, similar to Smets and Wouters (2007).[34]

Posterior estimates of parameters The mode estimate for the elasticity of substitution between stocks and bonds, λ_a, is close to 0.80, while the estimated for the elasticity of substitution between short- and long-term bonds, λ_b, is larger at 2.18.[35] The lower elasticity estimate for stocks is key to our result that large-scale stock purchases by the central bank would lead to larger portfolio rebalancing effects relative to long-term bond purchases.

The posterior estimates for the other parameters are by and large standard, and close to other estimates in the related DSGE literature. The habit parameter, ζ, has a posterior mode of 0.93, helping capture the high persistence in the consumption data, while the estimate for the investment adjustment cost parameter, κ_x, is close to 20, implying a fairly low elasticity of investment demand to Tobin's q. Similarly, the estimates for σ, ϑ, and ϖ imply, respectively, an elasticity of intertemporal substitution of 0.67, a labor supply elasticity close to 1.9, and an elasticity of capacity utilization with respect to the rental rate of capital of about 0.17.

The estimates for the price and wage adjustment cost parameters, κ_p and κ_w, indicate significant levels of price and wage stickiness with relatively flat Phillips curve slopes of 0.029 and 0.021 for prices and wages, respectively.[36] The estimates for the indexation parameters, ς_p and ς_w, are 0.14 and 0.65, respectively, indicating the importance of indexation for wage-setting, but not as much for prices.

The Taylor rule on the policy rate is fairly persistent with a mode ρ close to 0.91, while the estimates for the long-run reaction coefficients, a_π, a_y, and $a_{\Delta y}$ are 1.71, 0.11, and 0.43. Finally, the estimates for the output and debt response coefficients in the tax rule, τ_y and τ_b, are 0.84 and 0.57, respectively.

[34] To facilitate easier estimation, we also rescale some of the shocks. In particular, the consumption and investment shocks are rescaled as $\widehat{\upsilon}_t^{est} = \{(1-\zeta/\gamma)(1-\rho_\upsilon)/[(1+\zeta/\gamma)\sigma]\}\,\widehat{\upsilon}_t$ and $\widehat{z}_{x,t}^{est} = (1/\kappa_x)\,\widehat{z}_{x,t}$, respectively, while the portfolio shocks are rescaled as $\widehat{\gamma}_{b,t}^{est} = \{\psi/[\lambda_b(1-\gamma_b)]\}\,\widehat{\gamma}_{b,t}$ and $\widehat{\gamma}_{a,t}^{est} = \{\psi/[\lambda_s(1-\gamma_a)]\}\,\widehat{\gamma}_{a,t}$. Similarly, the markup shocks are rescaled as $\widehat{\theta}_{p,t}^{est} = \{(\eta_y-1)/\kappa_p\}\,\widehat{\theta}_{p,t}$ and $\widehat{\theta}_{w,t}^{est} = \{(\eta_n-1)/\kappa_w\}\,\widehat{\theta}_{w,t}$. These changes are without loss of generality in our log-linearized setup.

[35] Note that the latter is close to the bond elasticity estimate in Alpanda and Kabaca (2020).

[36] These estimates would be equivalent to *** and *** in the Calvo setup.

4 Results

In this section, we first analyze the transmission mechanisms of key shocks in the model using impulse responses and judge the model's performance in capturing U.S. macro-financial facts over the business cycle through model moments, forecast-error variance decompositions (FEVD), and historical decompositions of key model variables during the 2008 financial crisis and the 2020 coronavirus crisis. We then use the model to quantitatively evaluate the effects of large-scale stock purchases by the central bank, and compare these results to similar-sized long-term bond purchases.

4.1 Transmission mechanisms and model performance

Monetary policy and news shocks Figure 2 plots the impulse responses of key variables in the model to a 100 bps (annualized) innovation in the contemporaneous component of the monetary policy rule, $\varepsilon_{I,t}$. Note that period 0 in the figures depict the steady state before the shock occurs, while the shock occurs and its impact is felt in period 1.[37] The solid red lines depict the baseline case with the portfolio rebalancing effects present, while the dashed blue lines refer to the case where the term and risk premia do not change endogenously (i.e., stocks and bonds are assumed to be perfectly substitutable with $\lambda_a = \lambda_b = \infty$, and therefore the required returns on all three assets are equal $E_t r_{t+1} = E_t r_{L,t+1} = E_t r^s_{t+1}$).

The monetary policy shock increases the short-term interest rate, I_t, by about 1 pp at impact, while the long-term yield, $I_{L,t}$, increases by 34 bps based on the expectations hypothesis. Note that the term premium does not change endogenously here, since we have assumed that the government issues short- and long-term of bonds in constant proportion and thus, we have $q_{L,t}+b_{L,t}-q_{S,t}-b_{S,t} = 0$ for all t. The risk premium on equity drops, given the equilibrium decline in stock market values relative to the composite bond holdings of agents, $v_t + s_t - b_t$. This decrease in the risk premium is about 11 bps, and has a moderate impact on the results based on comparing the baseline case (solid red lines) with the alternative case where we shut off the portfolio rebalancing channel (dashed blue lines). The transmission of the monetary policy shock is quite standard in the model, except for this change in the risk premium. The increase in the risk-free rate translates into a comparable increase in the expected return from the asset portfolio, which in turn leads to a reduction in consumption demand, c_t, as well as a decline in Tobin's q and therefore a decline in investment demand, x_t. The resulting decline in aggregate demand results in a 0.28% decline in output and 0.14 percentage point (pp) decline in annualized inflation, along with a decline in labor demand and wages. Given the increase in the required return on equity, stock prices drop by about 1.24%, along with the decrease in the price of installed capital, q_t. In the absence of the portfolio rebalancing channel, the risk premium does not change, and therefore, the decrease in stock prices and the increase in the required return on stocks are slightly larger in magnitude. The impact on the real side of the economy is also slightly larger as a result, with output declining by an additional 8 bps relative to the baseline case.

[37] This is the convention followed in all the following figures as well.

The discussion above should not convey the impression that the portfolio rebalancing channel or portfolio shocks are relatively unimportant for business cycles. As we shall see later in this section, portfolio shocks do have important effects on macro-financial aggregates in the model. Furthermore, the portfolio rebalancing channel is critical in generating sizable effects from large-scale stock and bond purchases of the central bank, as we show in Section 4.2. For the standard business cycle shocks however, the endogenous component of the risk premium is not altered significantly enough to have a profound impact on the transmission of these shocks.[38]

Figure 3 plots the impulse responses for innovations to the news components of the monetary policy rule, $\varepsilon_{I,t}^{h}$, at horizons $h = 1, 4, 8$. The transmission of the monetary policy news shocks is by-and-large similar to that of the contemporaneous shock described in Figure 1. The peak impacts are delayed with the news shocks, but the contractionary impact of the shock starts to be felt from the impact period (which, remember, is depicted as period 1, while period 0 depicts the initial steady state prior to the shock). In fact, the delay in the impact generates expectations such that the peak impact on output and inflation becomes slightly larger at longer news horizons. This is a common problem in the DSGE literature called the "forward guidance puzzle", and is present in our setup as well.[39]

Portfolio shocks Figure 4 plots the impulse responses of model variables to 100 bps (annualized) innovations in the two portfolio shocks, $\gamma_{a,t}$ (solid red lines) and $\gamma_{b,t}$ (dashed blue lines), which affect the risk premium and term premium, respectively.

With the risk premium shock, the resulting increase in the required return on stocks, $E_t r_{t+1}^{s}$ reduces stock prices by about 0.93% at impact, and also leads to a 0.63 pp increase in the required return on the asset portfolio, $E_t r_{t+1}^{a}$. The latter causes consumption and investment demand to decline simultaneously, similar to the effects of "risk shocks" in Smets and Wouters (2007), and results in a 0.052% decline in aggregate output and a 2.3 bps decline in inflation. Note that the expected return on short- and long-term bonds do not affect the outcome significantly. This is due to the fact that the Fed reduces the policy rate, I_t, as inflation and output declines, and so $E_t r_{t+1} = I_t - E_t \pi_{t+1}$ does not change by much. Furthermore, the term premium stays constant by construction given our proportional bond supply rule assumption. Finally note that the risk premium actually increases slightly less than 100 bps in equilibrium, despite the 100 bps innovation in the risk premium shock. This is because of the portfolio rebalancing effect. In particular, as stock values decline and bond values increase (since long-term bond price, $q_{L,t}$, increases along with the decline in yields), the term, $v_t + s_t - b_t$, decreases slightly, which dampens the increase in the risk premium.

The transmission mechanism for the term premium shocks is similar, except now the increase in the expected return on the asset portfolio is due to the increase in the term premium rather

[38] Note also that the endogenous component of the term premium does not change by construction, given our assumption of proportional bond supply in equilibrium.

[39] See Alpanda and Kabaca (2020) for a similar setup with portfolio rebalancing, which can alleviate the forward guidance puzzle by creating a slight "discounting" in the *IS* (consumption) equation.

than the risk premium. In particular, the increase in the term premium results in an increase in long-term yields, $I_{L,t}$, and the required return on long-term bonds, $E_t r_{L,t+1}$. The resulting increase in the required return on the asset portfolio, $E_t r^a_{t+1}$, reduces aggregate demand, lowering output and inflation as before. Even though the required return on the asset portfolio increases by comparable amounts at impact for both the risk premium and the term premium shocks, the term premium shock is more persistent ($\rho_b = 0.90$ compared to $\rho_a = 0.74$), and therefore has more lasting effects on future expected returns. This in turn leads to larger effects on aggregate demand, with output falling by 0.15% and inflation declining by 8 bps at the peak. Also note that stock prices decline with term premium shocks as well (by 0.69%), as the required return on stocks increases along with the required return on long-term bonds. The *endogenous* change in the risk premium is insignificant however, since bond values decline along with stock values given the increase in bond yields, and therefore the stock-to-bond ratio, $v_t + s_t - b_t$, does not move by much.

Business cycle moments Table 5 lists the business cycle moments of key variables in the model versus their counterparts in the data. The model does a fairly good job in capturing the main contours of business cycle and financial facts in the data, although it generates slightly more volatile macro aggregates than the data to be able to match the financial moments better. The standard deviation of stock returns in the model is 9.6% compared to 8.7% in the data, and the model generates equity returns which have very low (and slightly negative) autocorrelation and moderate cross-correlation with output growth. The real return on long-term bonds in the model has a standard deviation of 2.8%, and bond returns have a low autocorrelation and moderately negative cross-correlation with output growth, by-and-large consistent with the data. The model also does a fair job in matching the volatility of short- and long-term bond quantities separately, even though only their difference is included as an observable in the estimation.

Forecast-error variance decompositions (FEVD) Table 6 shows the contribution of each shock to forecast error variance of key model variables at various forecast horizons. As expected, the innovations in the risk-premium shock, $\varepsilon_{a,t}$, accounts for most of the volatility (about 95%) in the required return on stocks in both short and long horizons. These shocks are also important for macro variables, accounting for about 13.3% of output growth volatility and 4.3% of inflation volatility unconditionally. Similarly, the term premium shocks, $\varepsilon_{b,t}$, account for a sizable portion of the volatility in long-term yields and the required return on long-term bonds in all horizons (between 33-35%). Their contribution to macro volatility is much lower however, accounting for only about 1% of output growth and inflation volatility in longer horizons. With a combined contribution of nearly 14% for output growth and 5.5% for inflation, portfolio shocks seem to be important to account for macroeconomic aggregates as well as financial returns.

The consumption, investment, and government expenditure shocks ($\varepsilon_{v,t}$, $\varepsilon_{x,t}$, and $\varepsilon_{g,t}$) have a combined contribution of close to 81% for the volatility in output growth at longer horizons, with consumption and investment shocks being the largest contributors, the latter reminiscent of the results in Justiniano et al. (2011). These three "demand" shocks also account for about 8% volatility in the required return on long-term bonds, while their contribution to stock returns is more limited at around 2%.

The three supply shocks ($\varepsilon_{z,t}$, $\varepsilon_{p,t}$, and $\varepsilon_{w,t}$) on the other hand have a more modest contribution for output growth (only 1% to 2%), but a far larger effect on inflation (91% in the 1-period ahead and about 74% in longer horizons). Their contribution is also sizable for short- and long-term bond yields and the required return on long-term bonds (about 26% for short-term and 31% for long-term yields in longer horizons), but more modest for stock returns at around 1.2%.

The contemporaneous and news shocks on monetary policy ($\varepsilon_{I,t}$ and $\varepsilon^h_{I,t}$ for $h = 1, ..., 8$) account for most of the volatility in short-term bond yields, at around 56% at the 1-period ahead forecast horizon, which decreases to about 34% in longer horizons. Note that the news shocks seem to be more important at medium-term and longer horizons. Monetary policy shocks have a combined contribution of about 3.5% for output growth and 9.8% for inflation volatility. Finally, the contemporaneous and news shocks on relative bond supply ($\varepsilon_{\Gamma,t}$ and $\varepsilon^h_{\Gamma,t}$ for $h = 1, ..., 8$) have a negligible contribution to the volatility in the macro aggregates and most financial variables.

Historical decompositions (HD) Figure 5 shows the historical decomposition of output growth, inflation, and the return on stocks during the post-2002 period, which includes the financial crisis of 2008 and the coronavirus crisis of 2020. The decline in output growth during the 2008 episode is primarily accounted by the risk-premium shocks, which is the main financial shock in the model. Demand shocks are also important for the decline, but relatively more important for the recovery from the crisis post-2008. Consistent with the findings in FEVD, supply shocks contribute less to the decline in output, but far more to the decline in inflation, during this period. Also, the realized return on stocks is almost exclusively captured by shocks to the risk premium, $\varepsilon_{a,t}$.

In the 2020 episode, the sharp decline and the fast recovery in output growth are captured mainly by demand shocks, while risk-premium shocks seem to have contributed positively to the recovery in output growth as well. The gradual increase in inflation in the subsequent periods is mainly attributed to adverse supply shocks, but the results suggest that monetary policy shocks (both contemporaneous and news) have also contributed partly to the increase in inflation as well as its subsequent decline in the post-Covid period.

4.2 Large-scale asset purchases

Stock purchases Figure 6 plots the results from our large-scale stock purchase experiment. To conduct this experiment, we assume that the central bank purchases 2.65% of the total outstanding equity over 4 quarters (i.e., s^{CB}_t gradually increases from 0 to 0.0265, and therefore the quantity of stocks at the hands of mutual funds, s_t, decreases from 1 to 0.9735). The central bank keeps these stocks on its balance sheet for another 8 quarters, and then sells them off gradually over the next 8 quarters after that. Thus, the central bank's balance sheet is fully normalized after 5 years. The size of the equity purchase (i.e., 2.65% of outstanding equity) is scaled to equal 4% of steady state (annualized) output, a magnitude similar to the size of the QE2 announcement of the Federal Reserve in late 2010. We also assume that the CB holds its policy rate at the ZLB during the initial year it purchases the equities. This is a reasonable assumption since we expect large-scale asset purchases to be primarily conducted during ZLB episodes. We will nevertheless conduct alternative experiments in the next section where we abstract from the ZLB constraint or extend it beyond 4 quarters.[40]

Our simulation assumes perfect foresight, so all agents take into account the whole 5-year profile for the central bank's equity holdings and the 1-year ZLB constraint on its policy rate.[41] In our baseline experiment (solid red lines), we assume that the stock purchases are financed solely through the issuance of short-term bonds, akin to issuing monetary base by the central bank. Long-term bonds are then residually determined through the government's budget constraint. In Figure 6, we also present an alternative simulation (dashed blue lines), where we assume that only half of the equity purchases are financed by short-term bonds, while the other half is financed by long-term bonds, potentially capturing the real-world tendency of governments to tilt their financing towards long-term bonds as long-term interest rates decline during LSAP episodes.

In the baseline simulation, the equity purchases by the central bank raises stock prices by about 1.5% at impact, but the *value* of stocks in the hands of the private sector, $v_t + s_t$, ultimately drops by about 2.5% at the peak. Coupled with the increase in short-term bonds, the relative stock holdings of mutual funds, $v_t + s_t - b_t$, drop significantly, which lowers the risk premium by about 66 bps based on the portfolio rebalancing channel. Note that the term premium also drops by a similar magnitude at the peak, as the large percent increase in short-term bonds leads to a decrease in the relative bond supply term, $q_{L,t} + b_{L,t} - q_{S,t} - b_{S,t}$. The drop in interest rates then leads to an increase in overall demand. In equilibrium, the required return on stocks fall by about 1.1 pp and the required return on the asset portfolio drops by about 0.9 pp. This leads to an increase in consumption of 0.36% as well as an increase in Tobin's q and therefore a rise in investment demand of about 1.3% at the peak. Consequently, output increases by 0.46%, labor increases by 0.34%, while inflation rises by 0.24 pp and real wages increase by 0.35%.

Note that the long-term yield falls by 37 bps, much less than the drop in the term premium, since short-term rates are expected to increase following the end of the ZLB period in quarter 4.[42]

[40] The 4-quarter assumption is also consistent with private sector expectations in November 2010 regarding the possible duration of ZLB during the QE2 episode in the U.S. (Chen et al., 2012). In reality, policy rates in the US stayed at the ZLB for far longer than 4 quarters, although this was by-and-large not expected by market participants a priori. Arguably, agents may expect a longer duration at the ZLB in future QE episodes; we thus conduct a sensitivity analysis on this duration in the next section.

[41] We use a first-order approximation of the model to obtain our results, and use *IRIS* routines for all our simulations (Benes et al., 2013b). These perfect-foresight exercises are conducted by feeding into the model a series of innovations in the equity purchase shock, s_t^{CB}, that generates the stock quantity (in private hands) profile described in the text and Figure 6, along with a series of innovations to the contemporaneous shock in the Taylor rule, $\varepsilon_{I,t}$, to ensure that the short-term rate stays constant for the first four quarters.

[42] The policy rate drops below 0 after 20 quarters following the stock purchase. This should not be interpreted as the nominal policy rate going into negative territory, since our figures are essentially "shock minus control" simulations that trace the differences in the transition paths with and without the LSAP policy following a severe negative shock that takes the economy to the ZLB constraint. Thus, our "control simulation" in the absence of the large-scale equity

Note also that the expected return on short-term bonds drops by 24 bps at impact despite the ZLB, given the increase in expected inflation. Thus, the required return on long-term bonds drops by about 0.67 pp, given the drops in both short-term bond expected returns and the term premium. This significantly strengthens the effect on the expected returns on the asset portfolio, and thereby amplifies the effect of the large-scale equity purchases on the real side of the economy as well.

In the alternative simulation (dashed blue lines), the effect on the term premium is smaller as the government converts half of the increase in short–term bonds from the equity purchase to long-term bonds, and therefore the term $q_{L,t}+b_{L,t}-q_{S,t}-b_{S,t}$ declines by less. The equity purchase still results in an equivalent drop in the risk premium, but now generates only a 0.6 pp drop in the required return on the asset portfolio, far lower than the 0.9 pp drop in the baseline simulation. Thus, the real effects are significantly lower as well, with output and inflation increasing by 0.31% and 0.15 pp, respectively.

Long-term bond purchases We now examine the case where the central bank purchases long-term bonds, instead of stocks, of a similar magnitude. We use the relative bond supply shocks, Γ_t, to implement this bond purchase experiment. To make the results comparable with equity purchases, we make the duration profile of the bond purchases and the ZLB constraint on the policy rate the same as in Figure 6.[43] Figure 7 plots the results (dashed blue lines), along with the baseline equity purchase results in the previous figure (solid red lines). We also consider a case where the central bank purchases half stocks and half long-term bonds totaling an equivalent amount.

With bond purchases, the value of long-term bonds outstanding drops by about 10.4%, and given the change in the relative holdings of bonds in private hands, $q_{L,t}+b_{L,t}-q_{S,t}-b_{L,t}$, the term premium drops by about 0.85 pp, driving long-term yields down by about 40 bps.[44] In equilibrium, the required return on short-term bonds drop by about 18 bps, mainly due to the increase in expected inflation. This, along with the drop in the term premium, results in a decrease of 0.93 pp in the required return on long-term bonds. Stock market values increase by about 0.79%, which results in a slight increase in the risk premium by about 9 bps at the peak, as the relative stock holdings of agents in their portfolios, $v_t+s_t-b_t$, rises. The overall drop in the required return on the asset portfolio is 59 bps, which results in an expansionary effect on aggregate demand. In particular,

purchase would entail the short rate being at 0 for 4 quarters, and then increasing slowly to its steady-state value along the transition path. For the "shock simulation" in the presence of the asset purchase, the path for the short rate would be only slightly different. In particular, the short rate would again equal 0 for 4 quarters, would go above the control case during quarters 4 through 20, and then below it for a while afterwards, while increasing to the steady state over time. Our figures here essentially depict the differences in these transition paths resulting from the shock and control simulations. Note that since we are simulating the linearized version of the model, we do not need to take a stand on the shock that drives the economy to the ZLB, and our results presented here (which technically start off from the steady state) would be the same if we first simulate an initial condition using a large adverse shock that takes the economy to the ZLB, and then calculating the difference in the transition paths between the shock and control simulations.

[43] The magnitude of this LSAP experiment is by and large comparable to the QE2 experiment conducted in Chen et al. (2012) and Alpanda and Kabaca (2020).

[44] This impact on U.S. long-term yields is well within range of the estimates for the QE2 episode. See Alpanda and Kabaca (2020), Bernanke (2012), and the papers cited therein.

output increases at the peak by about 0.31% as the consumption and investment components of output pick up, while the inflation rate increases by about 0.18 pp.

Compared with equity purchases, bond purchases are able to lower the required return on the asset portfolio slightly less, since asset portfolios are heavily skewed towards stocks rather than bonds (67% relative to 33%). Thus, large-scale equity purchases of the same magnitude have a larger effect on real variables as well. In particular, output increased by 0.31% in our bond-purchase experiment as opposed to 0.46% in the stock-purchase experiment. The results with half stock and half bond purchases are in between the fully stock and fully bond purchases.

Note that all three QE experiments result in significant effects on the real side of the economy, pointing to the importance of the portfolio rebalancing channel in our setup. In the previous section, we had found that the portfolio rebalancing channel provides a more limited transmission mechanism for conventional and news shocks on monetary policy (as well as other macro shocks not shown in the paper). The transmission of these shocks mainly hinged on the presence of nominal rigidities, similar to the standard New Keynesian set up (Smets and Wouters, 2007). This is not true however for unconventional policy shocks, which would have no effects on the economy if it were not for the presence of portfolio rebalancing channel in our setup.

5 Sensitivity Analysis

In this section, we investigate the robustness of our baseline results for large-scale equity purchases under alternative assumptions regarding the duration of the ZLB constraint and different values for the portfolio share and elasticity parameters.

5.1 Duration of the ZLB constraint

Figure 8 replicates the baseline results for the large-scale equity purchases in Figure 6 (solid red lines), as well as run alternative experiments where the ZLB duration on the policy rate is eliminated (dashed blue lines) or extended to 8 quarters (dotted black lines).

In both of these alternative simulations, the drops in the risk and term premia as a result of the equity purchase are very similar to those in the baseline case. Thus, the differences in results are basically due to the effects on the required return on short-term bonds, which feeds into the required return on other assets, and therefore the portfolio returns. In particular, in the absence of the ZLB constraint, the short-term yields start to increase immediately, which results in only a 69 bps decline in the required return on the asset portfolio, compared with 90 bps in the baseline case. Consequently, output and inflation increase less as well in the absence of the ZLB, by 0.38% and 18 bps, respectively, compared with 0.46% and 24 bps in the baseline. Similarly, extending the duration of the ZLB constraint to 8 quarters leads to a larger drop in the required return on the asset portfolio (0.96 pp), and therefore a larger increase in output and inflation than the baseline case (0.58% and 32 bps, respectively).

5.2 Portolio share parameters

In Section 3, we calibrated the portfolio share parameter, γ_a, to 0.33 based on the value of government bonds outstanding relative to corporate equity. Similarly, the share of short-term bonds in the bond subportfolio, γ_b, was calibrated to 0.42 based on the relative sizes of the short- and long-term bonds. In this section, we conduct sensitivity analysis on these parameters by amplifying or shrinking them 2-fold.[45]

In Figure 9, we assume γ_a equals 0.165 (dashed blue lines) or 0.66 (dotted black lines), and plot the results alongside the baseline case with 0.33 (solid red lines). The effects of large-scale equity purchases are larger with $\gamma_a = 0.165$ relative to the baseline case, as the share of stocks increases in the mutual funds' portfolios. The risk and term premia decline by 1.19 pp and 1.95 pp, respectively, relative to the 0.65 pp and 0.69 pp declines in the baseline case. Consequently, the required return on the asset portfolio now drops by about 2 pp, and the output impact at the peak is 0.88%, relative to 0.46% in the baseline case. Conversely, the results are weaker with $\gamma_a = 0.66$ relative to the baseline case, with only 0.32 pp and 0.17 pp drops in the risk and term premia, respectively, which leads to an expansion of output at the peak by about 0.15%.

Figure 10 repeats the exercise for γ_b, with possible values of 0.21 (dotted black lines) and 0.84 (dashed blue lines), alongside the baseline case of 0.42 (solid red lines). Although the risk premium drops by the same amount in all these cases, the drop in the term premium is larger relative to the baseline case when agents hold less short-term bonds in their portfolios (i.e., when $\gamma_b = 0.21$). This is because the percent increase in short-term bonds to finance the same equity purchase becomes larger as well. Consequently, the effects on macro variables are also more pronounced, with a peak impact on output and inflation of 0.80% and 44 bps, respectively. Conversely, the results are more muted when agents' bond portfolios are more skewed towards short-term bonds (e.g., when $\gamma_b = 0.84$), which leads to a smaller impact on macro aggregates relative to the baseline case.

5.3 Portfolio elasticity parameters

We next analyze the sensitivity of our baseline results to the elasticity parameters in the portfolio specification. Recall that in Section 3, we estimated the elasticity of substitution between stocks and bonds, λ_a, at around 0.80, while the elasticity of substitution between short- and long-term bonds, λ_b, was close to 2.18 at the mode of the posterior. We now conduct sensitivity analysis on these parameters by amplifying or shrinking them 5-fold, which, unlike the portfolio shares, do not affect the steady state.

We start with the elasticity of substitution between stocks and bonds, λ_a. Figure **??** shows the responses for the equity purchase experiment when we set λ_a to 0.16 (dashed blue lines) or to 4.0 (dotted black lines), with the former value capturing very low substitutability between stocks and

[45] Note that the portfolio share parameters affect the steady state levels of stock and bond values as well as the total size of the asset portfolio. For these exercises, we adjust the steady-state tax level parameter, Ξ, to satisfy the government's budget constraint in each iteration. The results are qualitatively similar if we keep the relative size of the total asset portfolio, a/y, the same as in the baseline case while adjusting γ_a.

bonds, while the latter capturing the case where stocks and bonds are close substitutes. The results indicate that equity purchases by the central bank would have larger impact on the economy if there is less substitutability between stocks and bonds. In particular, a lower degree of substitution amplifies the effects of a change in the relative holdings of stocks to bonds, $v_t + s_t - b_t$, resulting in a greater fall in the risk premium and therefore the required return on the asset portfolio, which in turn stimulates the economy further with a peak output impact of 1.06% compared to 0.46% in the baseline case. Also note that with $\lambda_a = 0.16$, stock prices increase by 3.84% at the peak, which implies a stock price multiplier of 1.45, in between the estimates of Barbon and Gianinazzi (2019) analyzing the stock ETF purchases of the BoJ and the *Demand System Asset Pricing* framework of Koijen and Yogo (2019) discussed in the Introduction. On the other hand, a higher elasticity of substitution between stocks and bonds with $\lambda_a = 4.0$ leads to weaker results. In this case, the action is solely through the decline in the term premium, which still drops by a comparable magnitude to the baseline case, while the risk premium does not materially change. The results on output is thus lower at 0.37%.

Finally, Figure 12 plots the results from alternative experiments where we set λ_b to 0.436 (dashed blue lines) or to 10.9 (dotted black lines), with the latter again implying close to perfect substitutability. Similar to λ_a, the output impact is predicted to be much larger (close to 2.5%) if there is less substitutability between short- and long-term bonds as well, since this leads to a far larger drop in the term premium and shows the importance of the term premium for the stock purchase results as well as for bond purchases. Conversely, a high elasticity of substitution leads to weaker results. In this case, the action is mainly through the decline in the risk premium, which drops by a similar magnitude to the baseline case, while the term premium now essentially does not move. The impact on output is therefore lower than the baseline case with an increase of 0.23%.

To summarize, our analysis in this section indicates that the effects of equity purchases would increase with the duration of the ZLB constraint, with the share of stocks in asset portfolios, and with lower elasticity of substitution between stocks and bonds or between short- and long-term bonds.

6 Conclusion

In this paper, we study the effects of large-scale stock and bond purchases in an estimated closed economy model with portfolio rebalancing effects. The latter arise from imperfect substitutability between stocks and bonds and between short- and long-term bonds in the portfolio preferences of mutual funds, which we introduce into an otherwise stylized DSGE model with nominal and real rigidities. This imperfect substitution between assets leads to lower risk and term premia on stocks and long-term bonds, which in turn boosts aggregate demand in the economy, as a response to large-scale equity purchases. We find that purchasing 2.65% of the outstanding equity (equivalent to 4% of steady-state output) for a duration of 5 years would stimulate output in the order of 0.46%. Since the portfolio share of stocks is larger than bonds and are less substitutable with short-term securities relative to long-term bonds, the effects of equity purchases on aggregate demand are found to be larger than a similar-sized long-term bond purchase.

Our results thus support the notion that the Fed be allowed to purchase a wider set of securities as part of its QE operations, including risk assets such as corporate stocks. As mentioned above, the model points to two key characteristics of stocks that make it a desirable candidate for QE operations: the first is the importance of stocks in investor portfolios and second is the low elasticity of substitution between stocks and short-term bonds (or equivalently bank reserves). Needless to say, there may also be potential costs in having the central bank hold a large share of private sector corporate equity for a prolonged period of time, as this may lead to more direct political influence on corporate governance and decision making as well as become a threat to the central bank's independence from the fiscal authority.[46] We have abstracted from these political economy considerations in our research, but incorporating some of these effects could provide interesting extensions for our setup.

Note also that, the Fed has conducted large-scale purchases in mortgage-backed securities (MBS) along with long-term government bonds following both the financial crisis of 2008 and the coronavirus crisis. As noted before, the Fed even purchased some corporate bond ETFs during the latter episode. Our model here can be extended to feature *securitized* household and firm debt to investigate the effects of these policies as well. We leave this extension to future research.

Relatedly, the "mutual funds" in our model arguably capture the role of non-bank financial institutions - NBFIs (e.g., pension funds, insurance companies, and various asset management firms etc.) in the system, but perhaps do not properly capture the role of commercial banks, which primarily extend credit to households and firms as well as hold a significant amount of bank reserves and government bonds on their balance sheet. Given bank reserves are only held by commercial banks while stocks are primarily held by NBFIs, large-scale stock purchases by the central bank would likely force simultaneous rebalancing in the "trading book" and "loan book" of banks as well as the asset portfolios of NBFIs. Whether this type of segmentation between banks and NBFIs would render QE more or less potent is an open question and we leave it for further research.

Note also that we have considered a closed economy setting in this paper, and have abstracted from the international trade and finance channels that would be present in an open economy setting (Alpanda and Kabaca, 2020). This change may potentially strengthen or weaken the domestic effects of large-scale asset purchases. In particular, QE in the U.S. would lead to a depreciation of the dollar, increasing U.S. net exports and thereby strengthening the domestic effects of QE. However, QE in the U.S. would also lead to a portfolio reallocation towards foreign assets (i.e., the financial channel), which would weaken the domestic effects of QE, especially if domestic and foreign assets are highly substitutable. Alpanda and Kabaca (2020) shows that the aforementioned international financial channel is stronger than the trade channel in their estimated setup, and therefore the domestic

[46] Broaddus and Goodfriend (2001) point out that the Fed's asset acquisition policies should minimize "the Fed's involvement in allocating credit across sectors of the economy" and "assets should be chosen to minimize the risk that political entanglements might undermine the Fed's independence and the effectiveness of monetary policy."

effects of QE are weaker in an open economy setting relative to a closed economy, at least for the case of large-scale *bond* purchases. This would likely be the result for *stock* purchases as well, at least qualitatively, but one would need a carefully estimated multi-country open economy framework to assess the quantitative effects of this change. We also leave this for further research.

References

[1] Adachi, K., K. Hiraki, and T. Kitamura (2021). "The Effects of the Bank of Japan's ETF Purchases on Risk Premia in the Stock Markets," Bank of Japan Working Paper Series No.21-E-3.

[2] Adjemian, S., H. Bastani, M. Juillard, F. Karamé, F. Mihoubi, G. Perendia, J. Pfeifer, M. Ratto, and S. Villemot (2011). "Dynare: Reference Manual, Version 5.1," Dynare Working Papers, 1, CEPREMAP.

[3] Alpanda, S. (2013). "Identifying the Role of Risk Shocks in the Business Cycle Using Stock Price Data," *Economic Inquiry*, 51, 304-335.

[4] Alpanda, S., and S. Kabaca (2020). "International Spillovers of LSAPs," *Journal of the European Economic Association*, 18, 342-391.

[5] Amano, R., and M. Shukayev (2015). "Risk Premium Shocks and the Zero Bound on Nominal Interest Rates," *Journal of Money, Credit and Banking*, 44, 1475-1505.

[6] An, S., and F. Schorfheide (2007). "Bayesian Analysis of DSGE Models," *Econometric Reviews*, 26, 211-219.

[7] Andres, J., J. D. Lopez-Salido, and E. Nelson (2004). "Tobin's imperfect asset substitution in optimizing general equilibrium," *Journal of Money, Credit and Banking*, 36, 665-690.

[8] Barbon A., and V. Gianinazzi (2019). "Quantitative Easing and Equity Prices: Evidence from the ETF Program of the Bank of Japan," *Review of Asset Pricing Studies*, 9, 210-255.

[9] Baumeister, C., and L. Benati (2013). "Unconventional Monetary Policy and the Great Recession: Estimating the Macroeconomic Effects of a Spread Compression at the Zero Lower Bound," *International Journal of Central Banking*, 9, 165-212.

[10] Benes, J., A. Berg, R. A. Portillo, and D. Vavra (2013a). "Modeling sterilized interventions and balance sheet effects of monetary policy in a New-Keynesian framework," IMF Working Paper No. 13/11.

[11] Benes, J., M. K. Johnston, and S. Plotnikov (2013b). IRIS Toolbox Release 20130208 (Macroeconomic modeling toolbox), software available at http://www.iris-toolbox.com.

[12] Bernanke, B. S. (2012). "Monetary Policy Since the Onset of the Crisis," Speech at the Federal Reserve Bank of Kansas City Economic Symposium, Jackson Hole, Wyoming, 31 August.

[13] Bhattarai, S., and C. Neely (2016). "A Survey of the Empirical Literature on US Unconventional Monetary Policy," Federal Reserve Bank of St. Louis Working Paper 2016-021A.

[14] Brainard, W. C. and J. Tobin (1968). "Pitfalls in Financial Model Building," *American Economic Review*, 58, 99-122.

[15] Broaddus, Jr. J. A., and M. Goodfriend (2001). "What Assets Should the Federal Reserve Buy?" *Federal Reserve Bank of Richmond Economic Quarterly*, 87, 7-22.

[16] Charoenwong B. R. Morck and Y. Wiwattanakantang (2021). "Bank of Japan Equity Purchases: The (Non-)Effects of Extreme Quantitative Easing," *Review of Finance*, 25, 713-743.

[17] Chen, H., V. Curdia, and A. Ferrero (2012). "The Macroeconomic Effects of Large-Scale Asset Purchase Programmes," *Economic Journal*, 122, F289-F315.

[18] Christensen, J. H. E., and G. D. Rudebusch (2012). "The Response of Interest Rates to U.S. and U.K. Quantitative Easing," Federal Reserve Bank of San Francisco Working Paper 2012-06.

[19] Christiano, L. J., R. Motto, and M. Rostagno (2014). "Risk Shocks," American Economic Review, 104, 27-65.

[20] Chung, H., J. P. Laforte, D. Reifschneider, and J. C. Williams (2012). "Have We Underestimated the Likelihood and Severity of Zero Lower Bound Events?," *Journal of Money, Credit and Banking*, 44, 47-82.

[21] Cohen, L. (2023). "The Effects of the BoJ's ETF Purchases on Equities and Corporate Investment," *Economic Modelling*, 129, 106540.

[22] Cooley, T. F., and E. C. Prescott (1995). "Economic Growth and Business Cycles," in *Frontiers of Business Cycle Research*, edited by T. F. Cooley. Princeton, NJ: Princeton University Press, pp. 1-38.

[23] Curdia, V., and M. Woodford (2011). "The Central Bank Balance Sheet as an Instrument of Monetary Policy," *Journal of Monetary Economics*, 58, 54-79.

[24] D'Amico, S., W. English, D. López-Salido, and E. Nelson (2012). "The Federal Reserve's Large-scale Asset Purchase Programmes: Rationale and Effects," *Economic Journal*, 122, F415-F446.

[25] Debortoli, D., J. Galí, and L. Gambetti (2020). "On the Empirical (Ir)Relevance of the Zero Lower Bound Constraint," *NBER Macroeconomics Annual 2019*, 34, 141-170.

[26] Del Negro, M., D. Giannone, M. P. Giannoni, and A. Tambalotti (2017). "Safety, Liquidity, and the Natural Rate of Interest," Federal Reserve Bank of New York Staff Report No. 812.

[27] Del Negro, Marco, Keshav Dogra, Aidan Gleich, Pranay Gundam, Donggyu Lee, Ramya Nallamotu, and Brian Pacula (2024). "The New York Fed DSGE Model: A Post-Covid Assessment," Federal Reserve Bank of New York Staff Reports No. 1082.

[28] Doh, T. (2010). "The efficacy of large-scale asset purchases at the zero lower bound," Federal Reserve Bank of Kansas City *Economic Review*, 95, 5-34.

[29] Engen, E. M., T. Laubach, D. L. Reifschneider (2015). "The Macroeconomic Effects of the Federal Reserve's Unconventional Monetary Policies," Finance and Economics Discussion Series No. 2015-5, Board of Governors of the Federal Reserve System.

[30] Erceg, Christopher, Marcin Kolasa, Jesper Lindé, Haroon Mumtaz and Pawel Zabczyk (2024). "Central Bank Exit Strategies: Domestic Transmission and International Spillovers," IMF Working Paper No. WP/24/73.

[31] Fernández-Villaverde, J. (2010). "The Econometrics of DSGE Models," *SERIEs*, 1, 3-49.

[32] Filippo Ferroni, Jonas D. M. Fisher, and Leonardo Melosi (2022). "Unusual Shocks in Our Usual Models," Federal Reserve Bank of Chicago Working Paper No. 2022-39.

[33] Fisher, J. D. M. (2015). "On the Structural Interpretation of the Smets-Wouters "Risk Premium" Shock," *Journal of Money, Credit and Banking*, 47, 511-516.

[34] Frankel, J. A. (1985). "Portfolio crowding-out, empirically estimated," *Quarterly Journal of Economics*, 100 (Supplement), 1041-1065.

[35] Gabaix, X., and Ralph S. J. Koijen (2021). "In Search of the Origins of Financial Fluctuations: The Inelastic Markets Hypothesis," NBER Working Paper No. 28967.

[36] Gabaix, X., Ralph S. J. Koijen, F. Mainardi, S. Oh, and M. Yogo (2023). "Asset demand of U.S. households," NBER Working Paper No. 32001.

[37] Gagnon, J., M. Raskin, J. Remache, and B. Sack (2011). "The financial market effects of the Federal Reserve's large-scale asset purchases," *International Journal of Central Banking*, 7, 3-43.

[38] Gambacorta, L., B., Hofmann, and G. Peersman (2014). "The Effectiveness of Unconventional Monetary Policy at the Zero Lower Bound: A Cross-Country Analysis," *Journal of Money, Credit and Banking*, 46, 615-642.

[39] Geweke, J. (1999): "Using simulation methods for Bayesian econometric models: Inference, development and communication," *Econometric Reviews*, 18, 1-73.

[40] Gilchrist, S., A. Ortiz, and E. Zakrajsek (2009). "Credit Risk and the Macroeconomy: Evidence from an Estimated DSGE Model," mimeo, Boston University, 2009.

[41] Greenwood, R. (2005). "Short- and long-term demand curves for stocks - theory and evidence on the dynamics of arbitrage," *Journal of Financial Economics*, 75, 607-649.

[42] Gurkaynak, R. S., B. Sack, and E. Swanson (2005). "The Sensitivity of Long-Term Interest Rates to Economic News: Evidence and Implications for Macroeconomic Models" *American Economic Review*, 95, 425-436.

[43] Hamilton, J. D., and J. C. Wu (2012). "The effectiveness of alternative monetary policy tools in a zero lower bound environment," *Journal of Money, Credit and Banking*, 44, 3-46.

[44] Harada, K., and T. Okimoto (2021). "The BOJ's ETF purchases and its effects on Nikkei 225 stocks," *International Review of Financial Analysis*, 77, 101826.

[45] Harrison, R. (2011). "Asset purchase policies and portfolio balance effects: a DSGE analysis," in *Interest rates, prices and liquidity*, edited by J. Chadha and S. Holly, Cambridge University Press.

[46] Ibbotson, R. G., and J. P. Harrington (2021). *Stocks, Bonds, Bills, and Inflation: SBBI Yearbook 2020*, Duff & Phelps, LLC.

[47] Jondeau, E., and M. Rockinger (2019). "Predicting Long-Term Financial Returns: VAR versus DSGE Model - A Horse Race," *Journal of Money, Credit and Banking*, 51, 2239-2291.

[48] Justiniano, A., G. Primiceri, and A. Tambalotti (2011). "Investment Shocks and the Relative Price of Investment," *Review of Economic Dynamics*, 14, 101-121.

[49] Kawamoto, T., T. Nakazawa, Y. Kishaba, K. Matsumura, and J. Nakajima (2023). "Estimating the macroeconomic effects of Japan's expansionary monetary policy under Quantitative and Qualitative Monetary Easing during 2013–2020," *Economic Analysis and Policy*, 78, 208-224.

[50] Koijen R. S. J., and M. Yogo (2019). "A demand system approach to asset pricing," *Journal of Political Economy*, 127, 1475-1515.

[51] Koijen R. S. J., and M. Yogo (forthcoming). "Which Investors Matter for Equity Valuations and Expected Returns?," *Review of Economic Studies.*

[52] Kolasa, M., and G. Wesolowski (2020). "International spillovers of quantitative easing," *Journal of International Economics*, 126, 103330.

[53] Krishnamurthy, A., and A. Vissing-Jorgensen (2011). "The effects of quantitative easing on interest rates: channels and implications for policy," NBER Working Paper No. 17555.

[54] Lloyd, S. P. (2021). "Overnight indexed swap-implied interest rate expectations," *Finance Research Letters*, 38, 101430.

[55] Occhino, F. (forthcoming). "Quantitative Easing and Direct Lending in Response to the COVID-19 Crisis," *Journal of Money, Credit and Banking.*

[56] Priftis, R., and L. Vogel, (2016). "The Portfolio Balance Mechanism and QE in the Euro Area," *The Manchester School*, 84, 84-105.

[57] Rogers, J. H., C. Scotti, and J. H. Wright (2014). "Evaluating Asset-Market Effects of Unconventional Monetary Policy: A Cross-Country Comparison," International Finance Discussion Papers No. 1101, Board of Governors of the Federal Reserve System.

[58] Scholes, M. S. (1972). "The market for securities: Substitution versus price pressure and the effects of information on share prices," *Journal of Business*, 45, 179-211.

[59] Shleifer, A. (1986). "Do demand curves for stocks slope down?" *Journal of Finance*, 41, 579-590.

[60] Smets, F., and R. Wouters (2007). "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach," *American Economic Review*, 97, 586-606.

[61] Swanson, E. T. (2021). "Measuring the effects of federal reserve forward guidance and asset purchases on financial markets," *Journal of Monetary Economics*, 118, 32-53.

[62] Tobin, J. (1969). "A general equilibrium approach to monetary theory," *Journal of Money, Credit and Banking*, 1, 15-29.

[63] Tobin, J., and W. C. Brainard (1963). "Financial Intermediaries and the Effectiveness of Monetary Controls," *American Economic Review*, 53, 383-400.

[64] Valchev, R. (2020). "Bond Convenience Yields and Exchange Rate Dynamics," *American Economic Journal: Macroeconomics*, 12, 124-166.

[65] Vitek, F. (2014). "Policy and Spillover Analysis in the World Economy: A Panel Dynamic Stochastic General Equilibrium Approach," IMF Working Paper No. 14/200.

[66] Woodford, M. (2001). "Fiscal requirements for price stability," NBER Working Paper No. 8072.

Table 1. Calibrated parameters		
	Symbol	Value
Deterministic growth factor (gross, qrt.)	γ	1.005
Inflation target (gross, qtr.)	π	1.005
Portfolio share - bonds in total portfolio	γ_a	0.33
- short in bond subportfolio	γ_b	0.42
Discount factor	$\widetilde{\beta} = \beta\gamma^{1-\sigma}$	0.976
Portfolio costs	$\psi = \Phi_1$	0.02
Coupon decay rate for long-term bonds	κ	0.975
Share of capital in production	α	0.33
Depreciation rate of capital	δ	0.025
Gross markup - price	$\theta_p = \eta_y / (1 - \eta_y)$	1.1
- wage	$\theta_w = \eta_n / (1 - \eta_n)$	1.1
Utilization cost level	κ_u	0.055
Tax level	Ξ	0.273

Table 2. Model steady-state ratios		
(relative to output)	Symbol	Value
Consumption	c/y	0.62
Investment	x/y	0.18
Government expenditure	g/y	0.20
Wages	wn/y	0.67
Dividends	$d/y = 1 - wn/y - x/y$	0.15
Capital stock (ann.)	$k_{-1}/(4y)$	1.5079
Stocks (ann.)	$v/(4y)$	1.5154
Short-term gov. bonds (ann.)	$q_S b_S/(4y)$	0.3135
Long-term gov. bonds (ann.)	$q_L b_L/(4y)$	0.4329

Table 3. Estimated structural parameters						
			Posterior distribution			
	Symbol	Prior dist.[a]	Mode	Mean	90% HPD interval	
Elasticity of substitution: equity vs. bonds	λ_a	B(2, 0.5)	0.7997	0.9367	0.5854	1.2755
short vs. long bonds	λ_b	B(2, 0.5)	2.1793	2.3039	1.6174	2.9792
Habit in consumption	ζ	B(0.5, 0.15)	0.9342	0.9296	0.9019	0.9586
Inverse elasticity of intertemp. substitution	σ	G(2, 0.5)	1.4816	1.5464	1.0308	2.0398
Inverse Frisch-elasticity of labor supply	ϑ	G(2, 0.5)	0.5252	0.5855	0.3580	0.8024
Utilization cost elasticity	ϖ	B(1, 0.15)	0.1663	0.1748	0.1348	0.2146
Investment adjustment cost	κ_x	G(5, 1.5)	20.1973	20.4684	17.9446	22.8948
Adjustment cost: price	$\kappa_p/100$	G(2, 0.25)	3.4345	3.4017	2.8923	3.9009
wage	$\kappa_w/100$	G(2, 0.25)	4.7120	4.7275	4.1547	5.3115
Indexation: price	ς_p	B(0.5, 0.15)	0.1382	0.1717	0.0679	0.2703
wage	ς_w	B(0.5, 0.15)	0.6473	0.6479	0.4513	0.8576
Taylor rule: persistence	ρ	B(0.5, 0.15)	0.9005	0.9029	0.8814	0.9260
inflation	a_π	G(1.5, 0.15)	1.7172	1.8785	1.4700	2.2871
output gap	a_y	G(0.5, 0.15)	0.1119	0.1145	0.0605	0.1652
output growth	$a_{\Delta y}$	G(0.5, 0.15)	0.4310	0.4634	0.2757	0.6462
Tax rule: output	τ_y	G(1, 0.15)	0.8436	0.8793	0.6612	1.0993
gov. debt	τ_b	G(1, 0.15)	0.5652	0.6485	0.4330	0.8550

a Prior distributions: B: beta, G: gamma, IG: inverse gamma.

Table 4. Estimated shock parameters

	Symbol	Prior dist.[a]	Posterior distribution			
			Mode	Mean	90% HPD interval	
Persistence: risk premium	ρ_a	B(0.5, 0.15)	0.7411	0.7448	0.7138	0.7755
term premium	ρ_b	B(0.5, 0.15)	0.9041	0.9042	0.8809	0.9277
preference	ρ_υ	B(0.5, 0.15)	0.1304	0.1468	0.0586	0.2331
investment	ρ_x	B(0.5, 0.15)	0.1238	0.1419	0.0676	0.2132
government exp.	ρ_g	B(0.5, 0.15)	0.9697	0.9676	0.9539	0.9816
productivity	ρ_z	B(0.5, 0.15)	0.8977	0.8995	0.8819	0.9170
price	ρ_p	B(0.5, 0.15)	0.7403	0.7279	0.6676	0.7880
wage	ρ_w	B(0.5, 0.15)	0.1362	0.1586	0.0793	0.2342
monetary policy	ρ_I	B(0.5, 0.15)	0.1945	0.2088	0.1110	0.3102
bond supply	ρ_Γ	B(0.5, 0.15)	0.9724	0.9706	0.9552	0.9865
St. dev.: risk premium	σ_a	IG(0.005, ∞)	0.0289	0.0286	0.0245	0.0326
term premium	σ_b	IG(0.005, ∞)	0.0028	0.0030	0.0024	0.0035
preference	σ_υ	IG(0.005, ∞)	0.0048	0.0048	0.0043	0.0053
investment	σ_x	IG(0.005, ∞)	0.0342	0.0338	0.0301	0.0376
government exp.	σ_g	IG(0.005, ∞)	0.0163	0.0164	0.0152	0.0176
productivity	σ_z	IG(0.005, ∞)	0.0075	0.0076	0.0070	0.0082
price	σ_p	IG(0.005, ∞)	0.0011	0.0012	0.0010	0.0014
wage	σ_w	IG(0.005, ∞)	0.0129	0.0129	0.0115	0.0143
monetary policy (MP)	σ_I	IG(0.005, ∞)	0.0010	0.0010	0.0008	0.0013
bond supply	σ_Γ	IG(0.005, ∞)	0.0235	0.0237	0.0219	0.0253
MP news st. dev.: 1-period ahead	$\sigma_{I,1}$	IG(0.005, ∞)	0.0009	0.0009	0.0007	0.0011
2-period ahead	$\sigma_{I,2}$	IG(0.005, ∞)	0.0008	0.0008	0.0007	0.0010
3-period ahead	$\sigma_{I,3}$	IG(0.005, ∞)	0.0009	0.0009	0.0007	0.0011
4-period ahead	$\sigma_{I,4}$	IG(0.005, ∞)	0.0009	0.0009	0.0007	0.0011
5-period ahead	$\sigma_{I,5}$	IG(0.005, ∞)	0.0009	0.0009	0.0007	0.0011
6-period ahead	$\sigma_{I,6}$	IG(0.005, ∞)	0.0009	0.0009	0.0007	0.0011
7-period ahead	$\sigma_{I,7}$	IG(0.005, ∞)	0.0009	0.0009	0.0007	0.0011
8-period ahead	$\sigma_{I,8}$	IG(0.005, ∞)	0.0009	0.0009	0.0007	0.0011

a Prior distributions: B: beta, G: gamma, IG: inverse gamma.

Table 5. Business Cycle Moments in Data vs. Model (%)						
	Data (1960Q1-2023Q4)			Model[a]		
	st.-dev.	**autocorr.**	**corr(., Δy)**	**st.-dev.**	**autocorr.**	**corr(., Δy)**
$\Delta y_t = y_t - y_{t-1}$	1.07	1.04	100.00	1.07	19.34	100.00
Δc	1.05	-6.47	82.53	1.16	17.26	70.35
Δx	4.09	11.47	77.50	3.82	16.84	68.04
Δn	1.37	3.22	82.48	1.29	3.20	69.06
Δw	0.96	-11.45	-32.05	1.38	11.71	30.49
π	0.58	88.21	-7.48	0.71	82.76	1.68
I	0.86	97.31	-6.31	0.84	93.56	-2.97
I_L	0.69	98.79	-0.72	0.45	94.31	-3.46
r^s	8.66	4.67	5.01	9.63	-11.73	23.12
r_L	2.82	34.46	-17.53	2.80	10.95	-10.77
$\Delta(q_S + b_S)$	6.04	21.93	-36.91	4.58	2.31	-5.58
$\Delta(q_L + b_L)$	3.38	51.01	16.05	3.54	6.45	-9.23

[a] The model moments are calculated using the posterior mode estimates of the parameters.

Table 6. Forecast-Error Variance Decomposition (FEVD) of Model Variables (%)

	$\varepsilon_{a,t}$	$\varepsilon_{b,t}$	$\varepsilon_{v,t}$	$\varepsilon_{x,t}$	$\varepsilon_{g,t}$	$\varepsilon_{z,t}$	$\varepsilon_{p,t}$	$\varepsilon_{w,t}$	$\varepsilon_{I,t}$	$\sum_{h=1}^{8}\varepsilon_{I,t}^{h}$	$\varepsilon_{\Gamma,t}$	$\sum_{h=1}^{8}\varepsilon_{\Gamma,t}^{h}$
1-period ahead												
Δy	9.0	0.4	40.2	38.9	10.1	0.1	0.2	0.1	0.2	0.9	0.0	0.0
Δc	6.9	0.2	92.3	0.1	0.0	0.0	0.1	0.0	0.1	0.3	0.0	0.0
Δx	3.3	0.2	0.1	95.2	0.0	0.1	0.3	0.1	0.1	0.7	0.0	0.0
π	2.6	0.5	1.2	1.4	0.0	10.8	69.2	10.8	0.2	3.1	0.0	0.2
I	4.4	0.4	10.4	3.8	1.8	2.7	17.6	2.7	54.5	1.7	0.0	0.1
I_L	10.2	40.4	4.9	1.6	1.8	9.0	11.2	5.4	5.6	9.1	0.3	0.6
r^s	94.6	0.8	0.3	2.0	0.0	0.6	0.0	0.7	0.4	0.6	0.0	0.0
r_L	10.2	33.4	4.9	1.8	1.6	10.6	18.8	6.9	4.5	6.7	0.2	0.4
8-period ahead												
Δy	12.2	0.7	37.7	35.7	9.1	0.5	1.0	0.3	0.4	2.5	0.0	0.1
Δc	9.8	0.4	87.7	0.2	0.0	0.1	0.4	0.1	0.2	1.1	0.0	0.0
Δx	4.7	0.4	0.5	90.7	0.0	0.5	0.8	0.3	0.2	1.9	0.0	0.1
π	4.5	1.1	1.3	4.6	0.0	16.0	49.5	13.1	0.6	8.5	0.1	0.7
I	12.0	1.8	5.8	0.5	0.8	8.0	20.8	6.5	11.6	31.5	0.1	0.7
I_L	12.7	26.7	5.1	4.7	2.6	12.2	10.0	6.4	3.6	14.9	0.2	1.0
r^s	95.0	0.8	0.3	1.7	0.0	0.5	0.1	0.6	0.4	0.6	0.0	0.0
r_L	9.4	34.9	4.5	2.0	1.4	9.8	17.9	6.5	4.9	8.0	0.2	0.5
∞-period ahead (unconditional)												
Δy	13.3	0.8	36.6	34.8	8.7	0.6	1.2	0.4	0.4	3.1	0.0	0.1
Δc	10.7	0.4	86.2	0.3	0.0	0.2	0.5	0.1	0.2	1.3	0.0	0.0
Δx	5.2	0.4	0.6	89.1	0.1	0.6	1.0	0.4	0.2	2.4	0.0	0.1
π	4.3	1.2	1.3	7.4	0.4	16.5	45.5	12.3	0.6	9.2	0.1	1.3
I	12.6	2.9	5.2	7.0	3.5	10.6	14.0	6.2	7.1	27.0	0.3	3.5
I_L	9.8	18.9	4.9	15.1	8.5	12.7	6.8	5.4	2.5	13.7	0.2	1.7
r^s	94.8	0.8	0.3	1.7	0.0	0.5	0.1	0.6	0.4	0.7	0.0	0.0
r_L	9.6	34.0	4.5	2.1	1.5	9.6	17.5	6.3	4.8	9.3	0.2	0.7

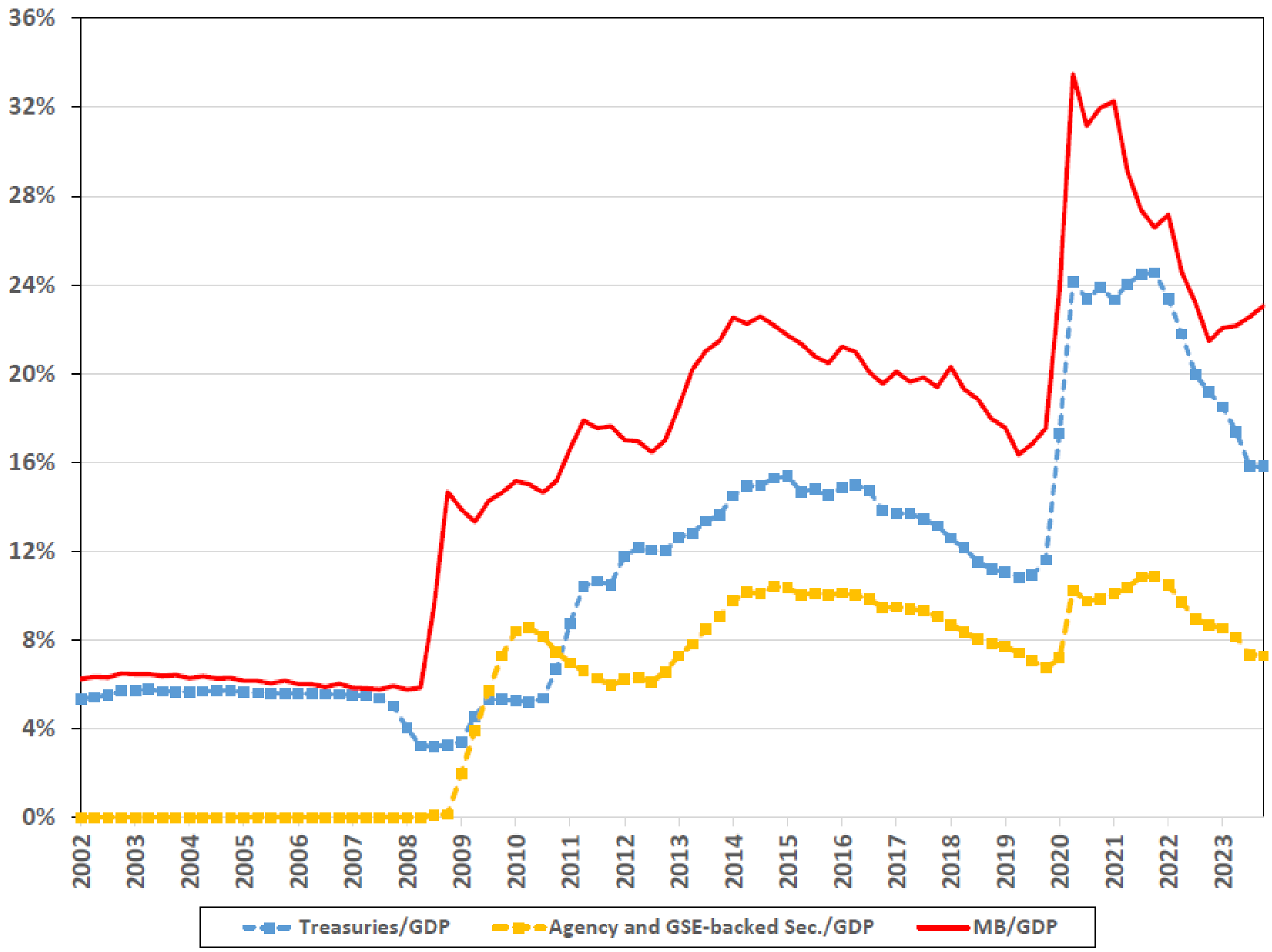

Figure 1: The Monetary Base (MB) and the value of Treasuries and Agency & GSE-backed securities held by the Federal Reserve (as percent of Nominal GDP).

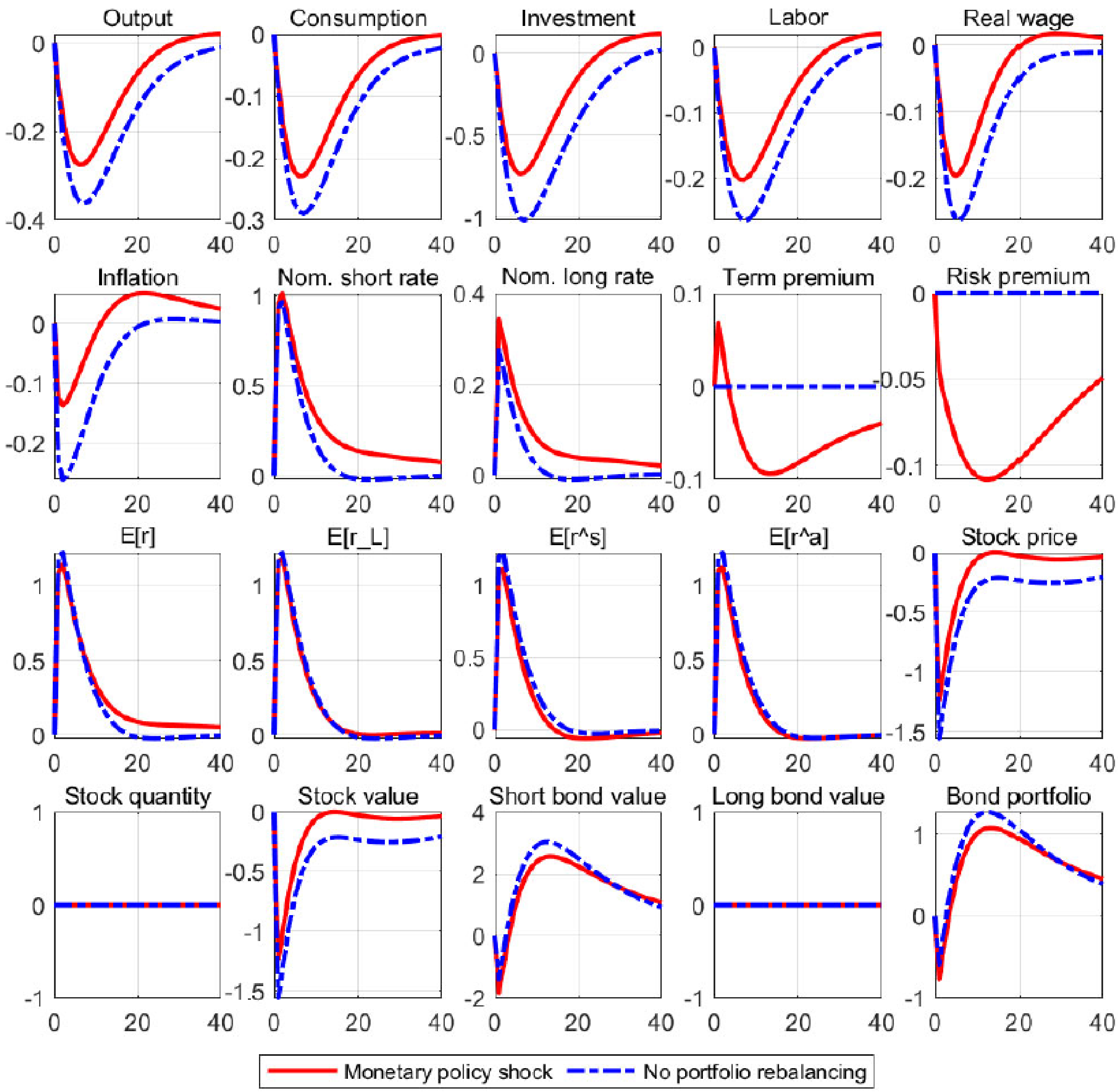

Figure 2: Impulse responses (in %) of model variables to a 100 bps (annualized) innovation in the contemporaneous component of the monetary policy shock. Solid red lines depict the baseline case with the portfolio rebalancing channel present, while the dashed blue lines exclude the latter by assuming that all assets are perfectly substitutable (i.e., $\lambda_a = \lambda_b = \infty$).

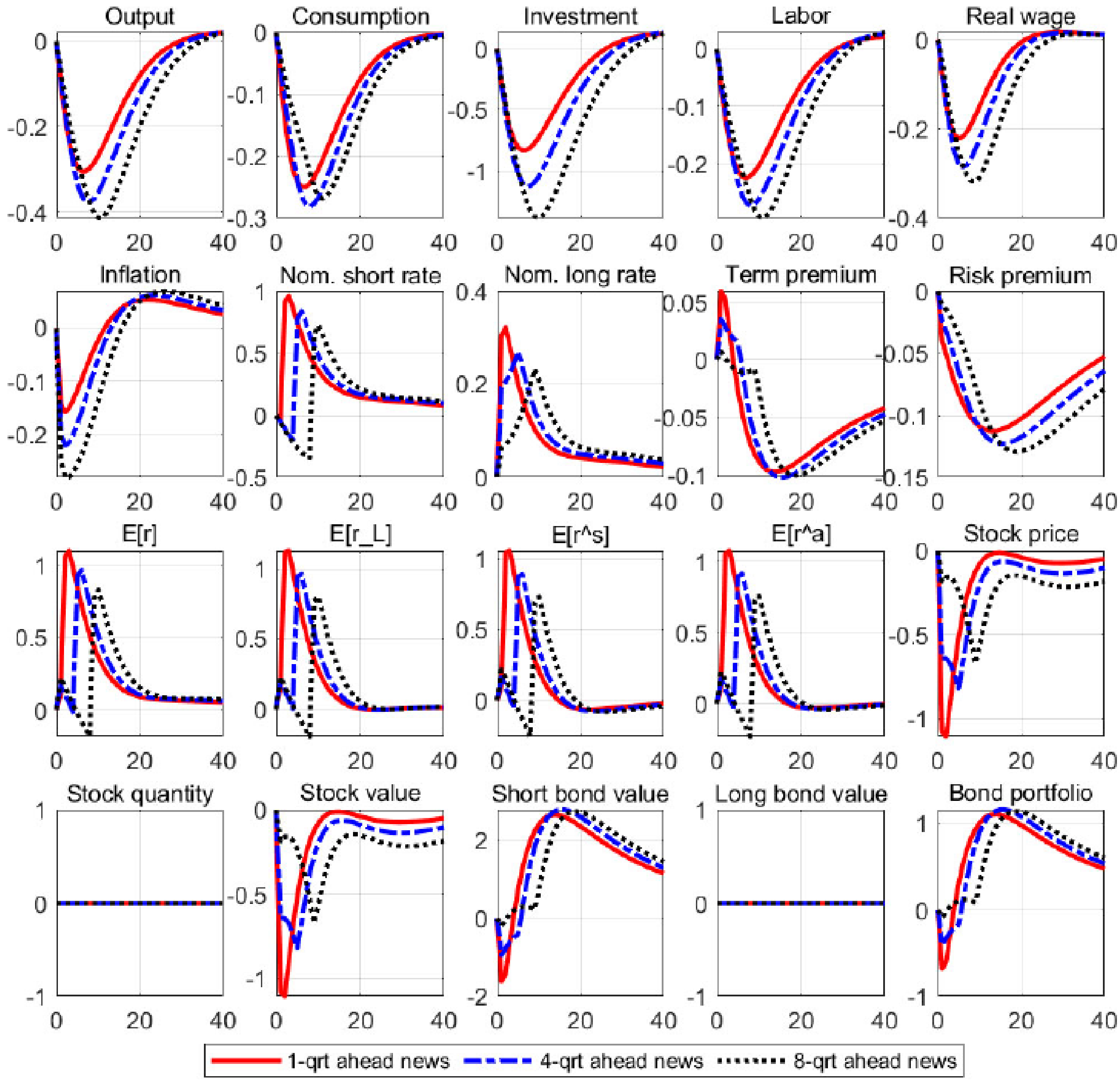

Figure 3: Impulse responses (in %) of model variables to a 100 bps (annualized) innovation in the news component of the monetary policy shock. Solid red lines depict the case at 1-period ahead, dashed blue lines at 4-period ahead, and black dotted lines at 8-period ahead news shocks.

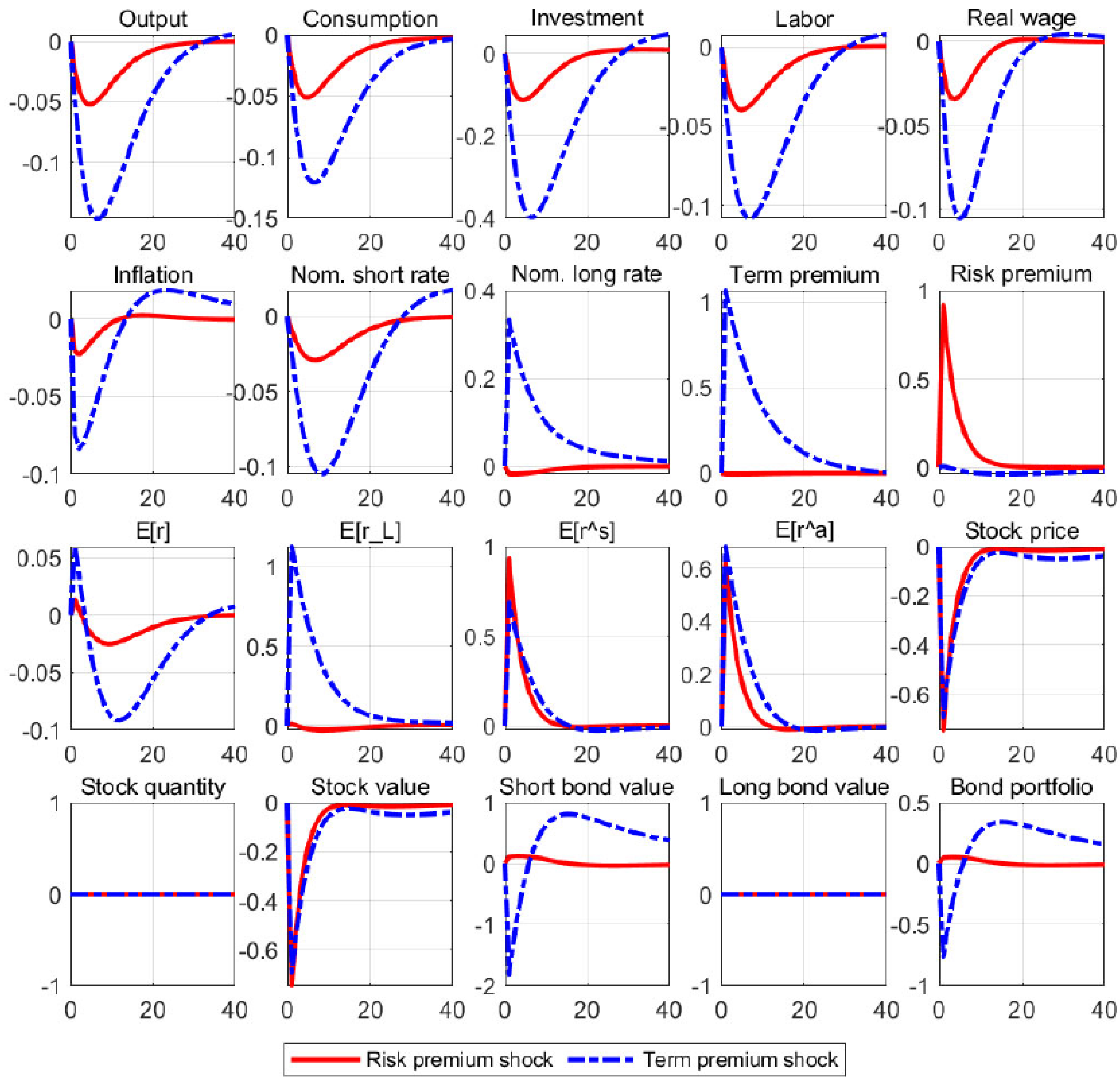

Figure 4: Impulse responses (in %) of model variables to a 100 bps (annualized) innovation in the risk premium shock, $\gamma_{a,t}$, (solid red lines) and term premium shock, $\gamma_{b,t}$ (dashed blue lines).

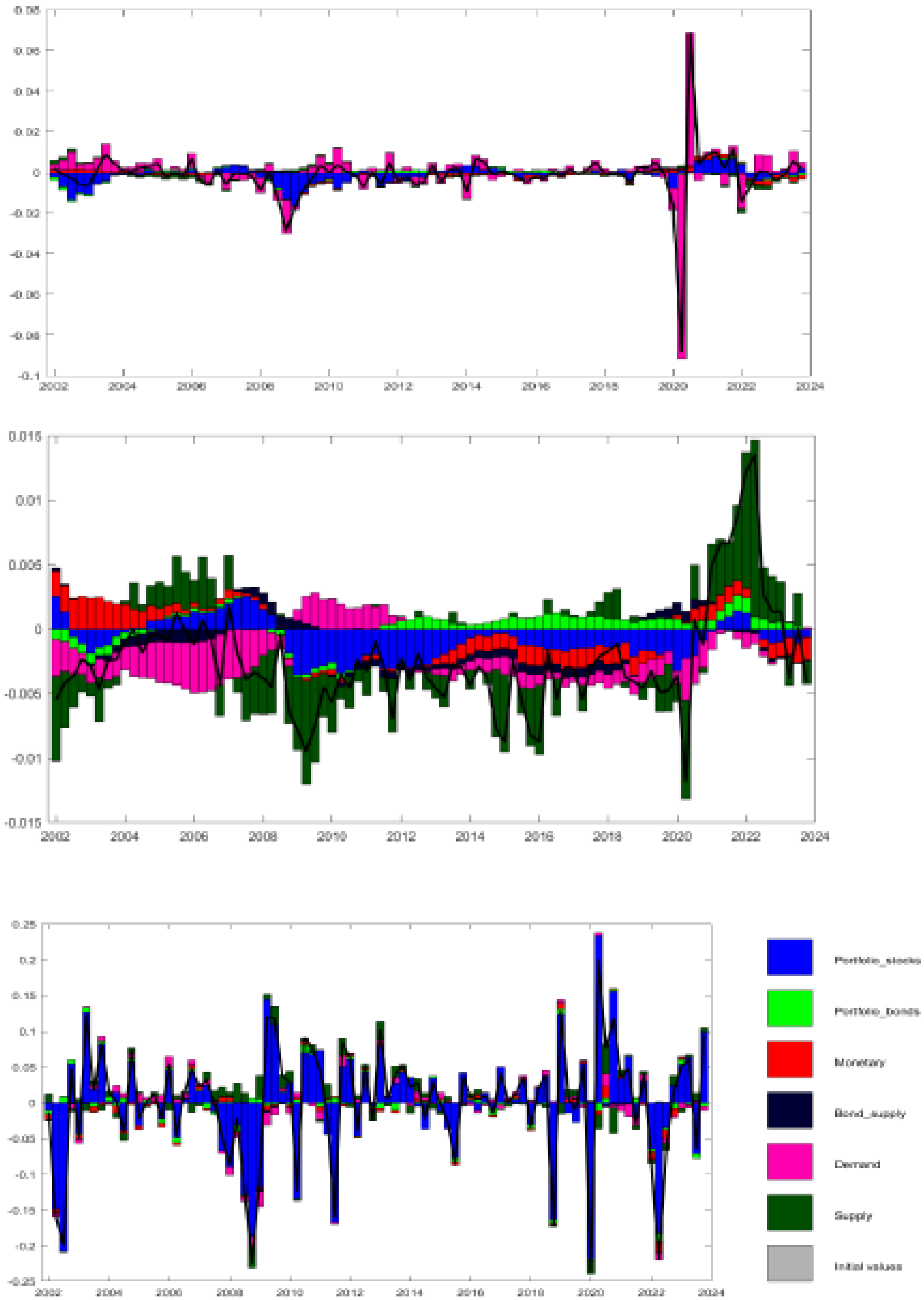

Figure 5: Historical decomposition of output growth Δy_t (top panel), inflation rate π_t (middle panel), and return on stocks r_t^s (bottom panel) between 2002Q1-2023Q4.

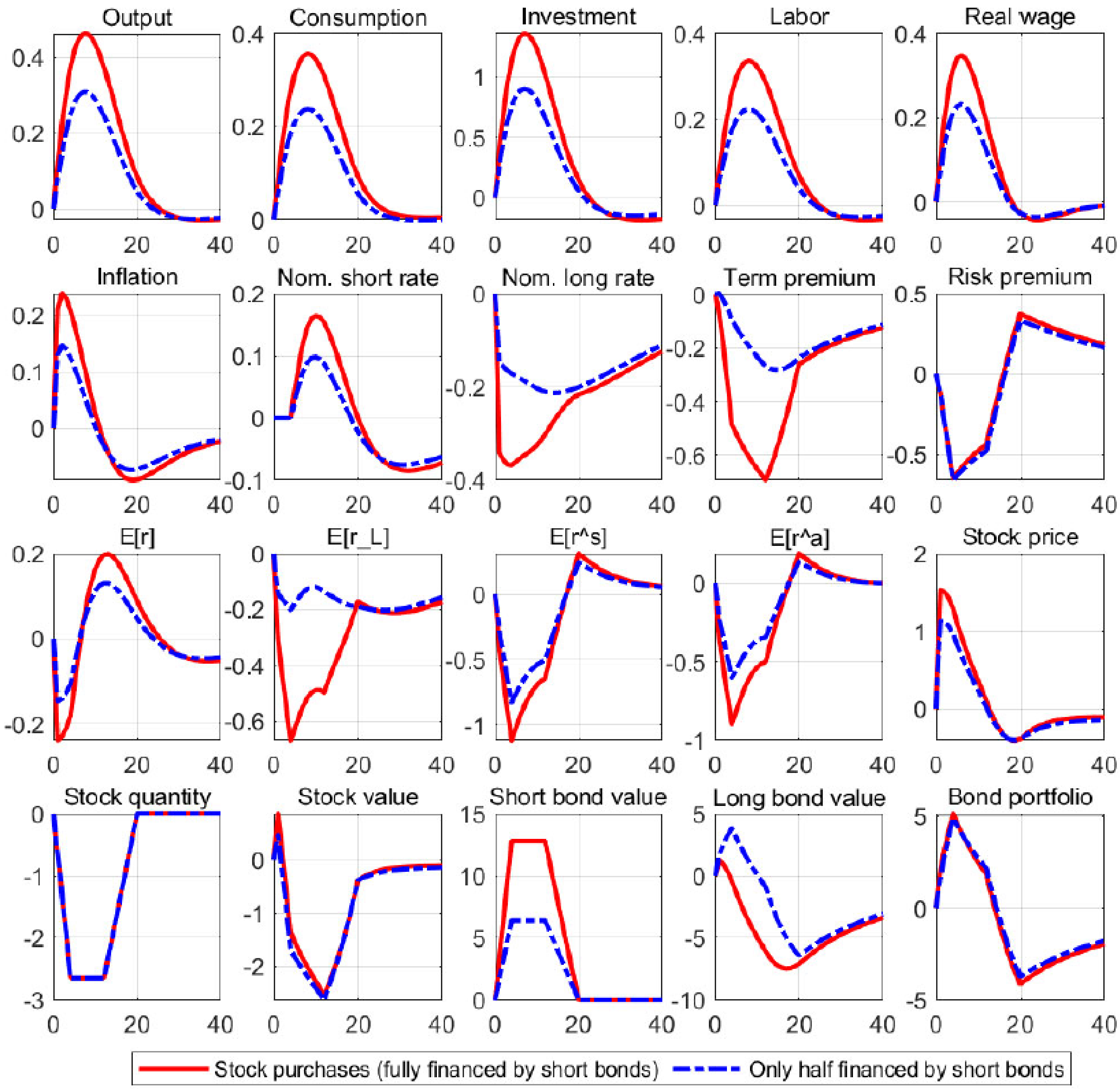

Figure 6: The effects of large-scale stock purchases on model variables (in %). The Central (CB) is assumed to buy 2.65% of outstanding equity over 4 quarters, hold them for another 8 quarters, and gradually sell them off over the next 8 quarters. The CB also holds the policy rate at the ZLB for 4 quarters. The baseline simulation (solid red lines) assumes the purchases are fully financed by short-term bonds, while the alternative simulation (dashed blue lines) assumes only half is financed by short-term bonds.

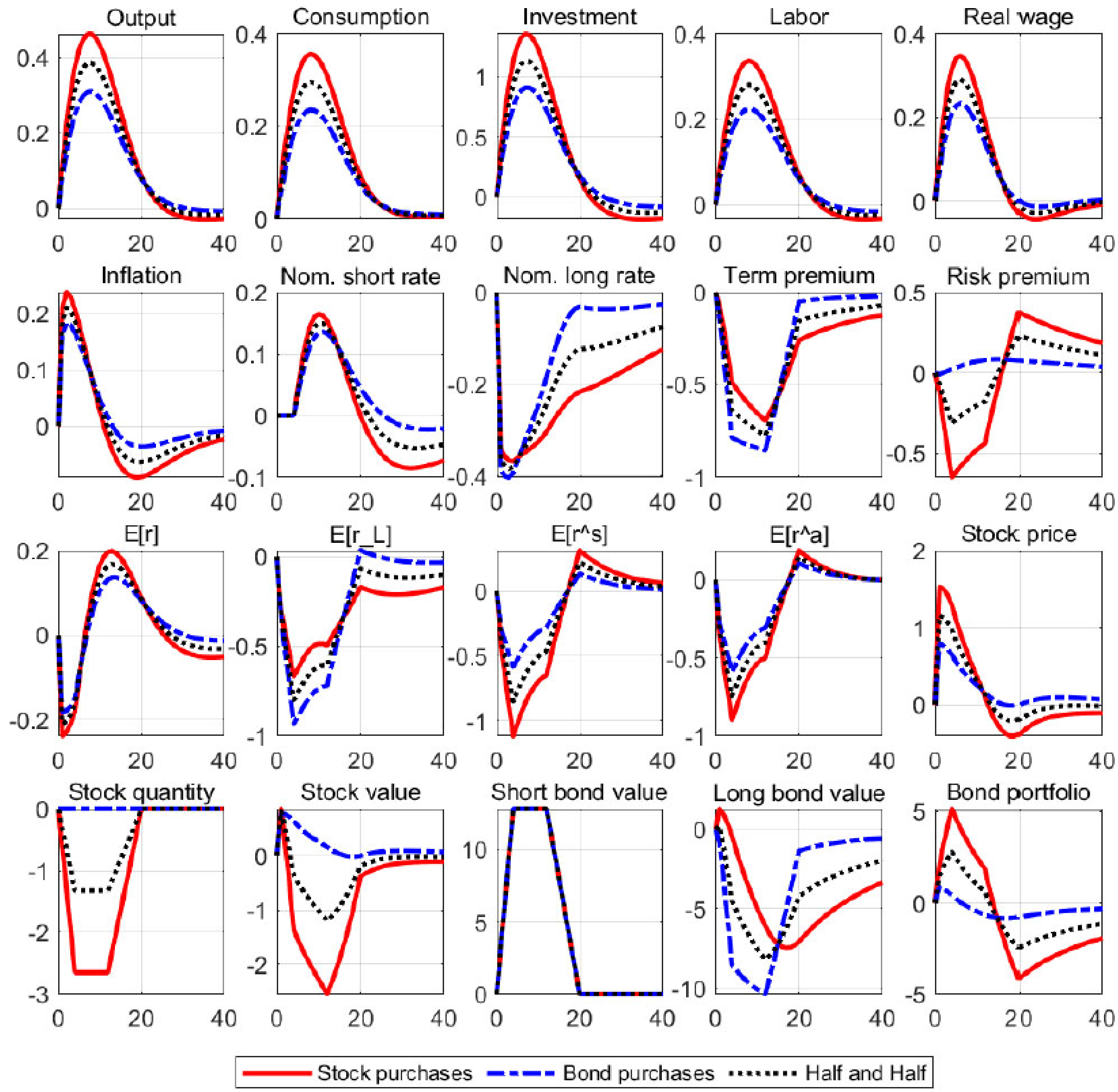

Figure 7: The effects of large-scale bond purchases compared to large-scale stock purchases. The magnitude and duration of the bond purchases are scaled to equal those in the stock purchase experiment in Figure 6.

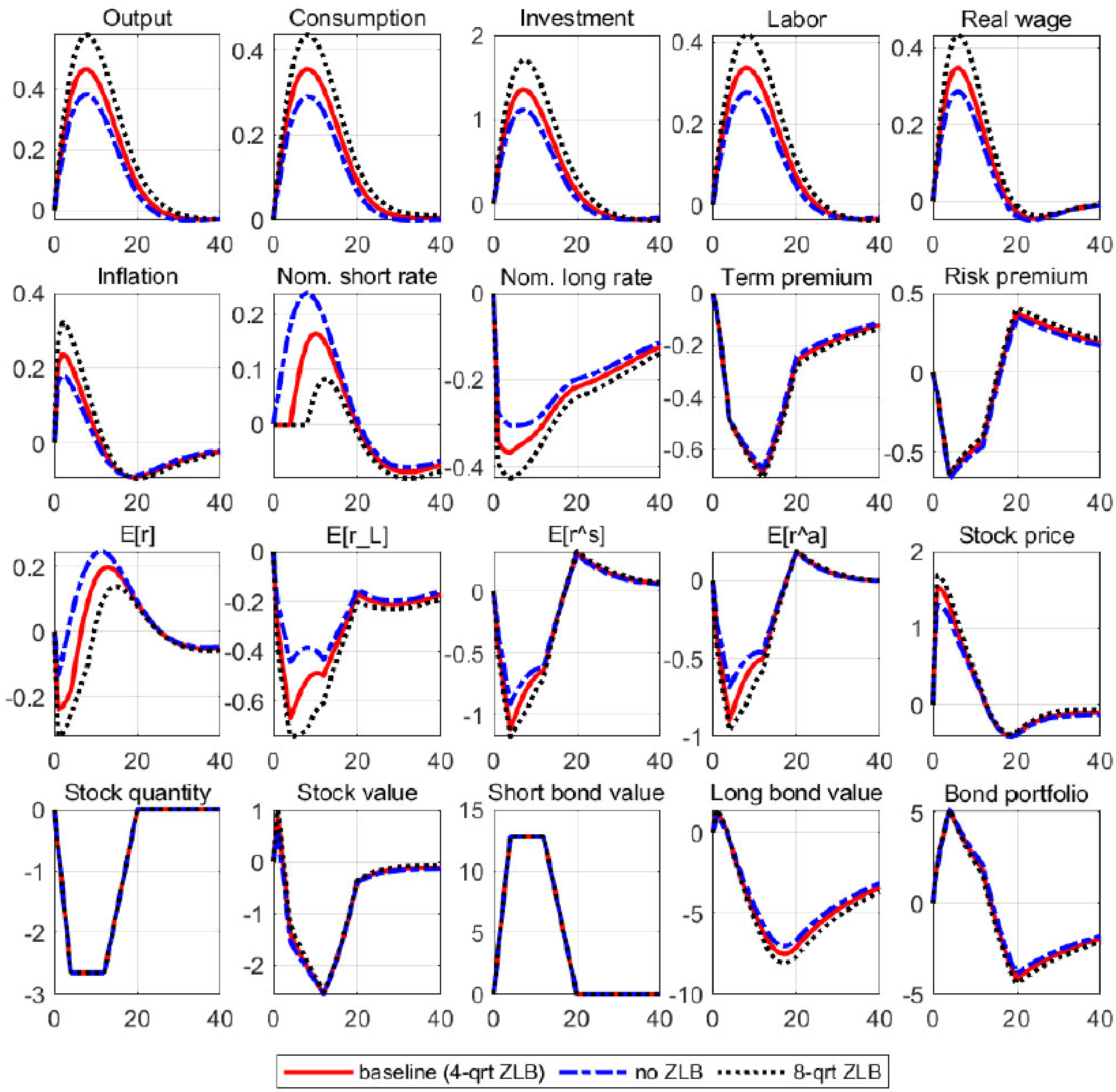

Figure 8: The effects of large-scale stock purchases (in %) under different assumptions regarding ZLB duration on the policy rate. Solid red lines depict the baseline results with 4 quarter ZLB as in Figure 6.

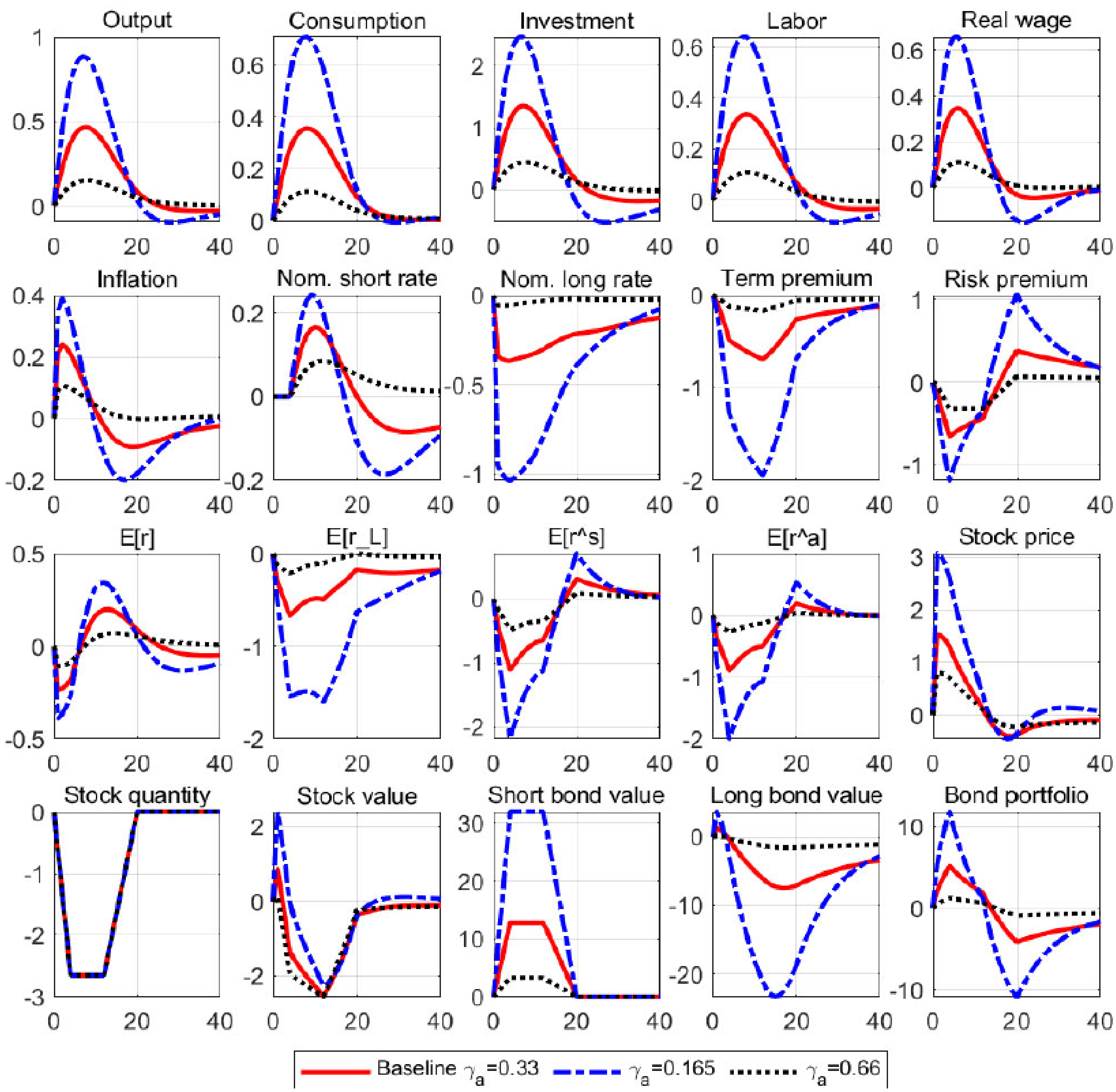

Figure 9: The effects of large-scale stock purchases (in %) under different values for the steady-state bond-share portfolio parameter, γ_a. Solid red lines depict the baseline results with $\gamma_a = 0.33$.

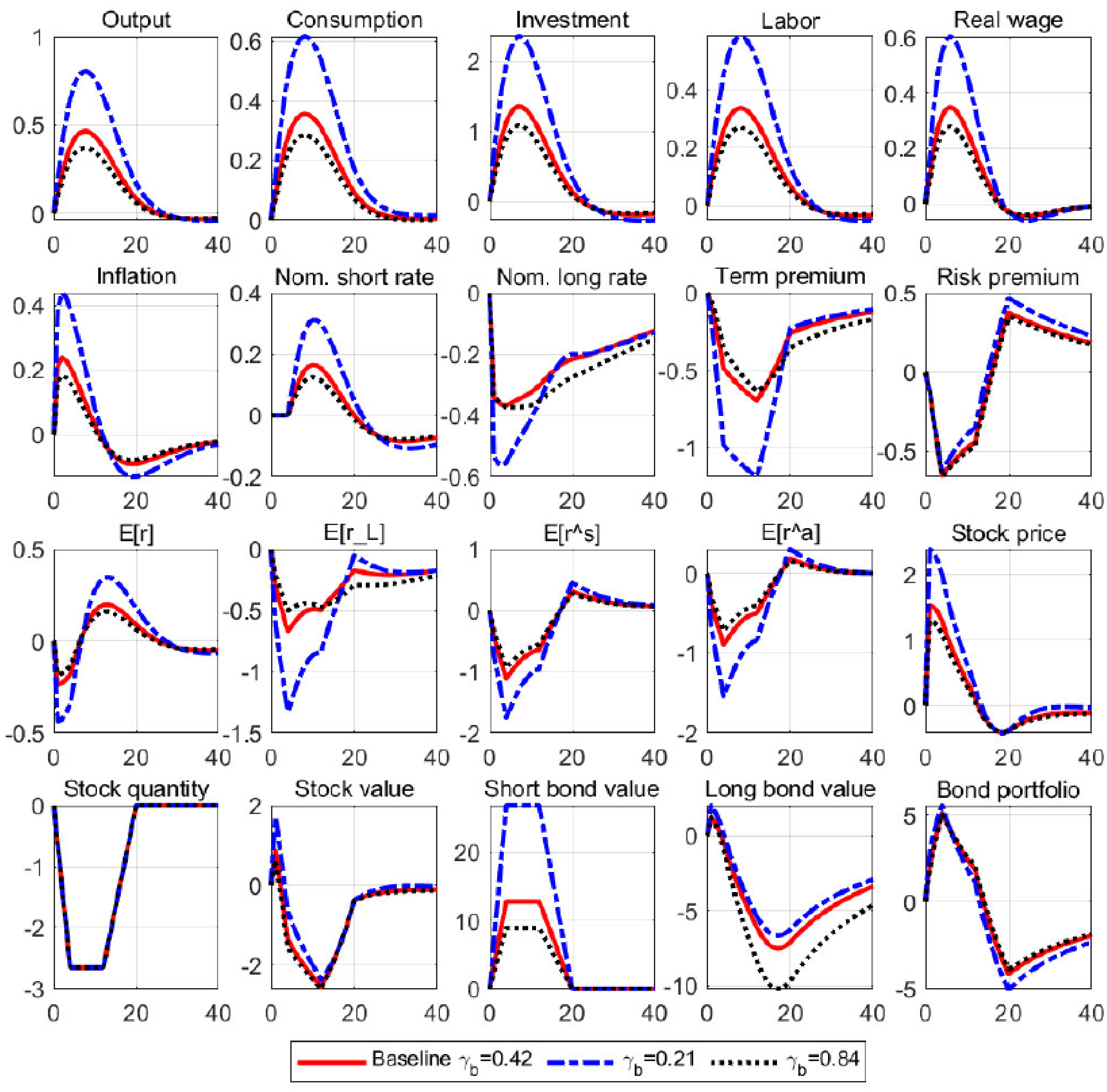

Figure 10: The effects of large-scale stock purchases (in %) under different values for the steady-state short-term bond share parameter, γ_b. Solid red lines depict the baseline results with $\gamma_b = 0.42$.

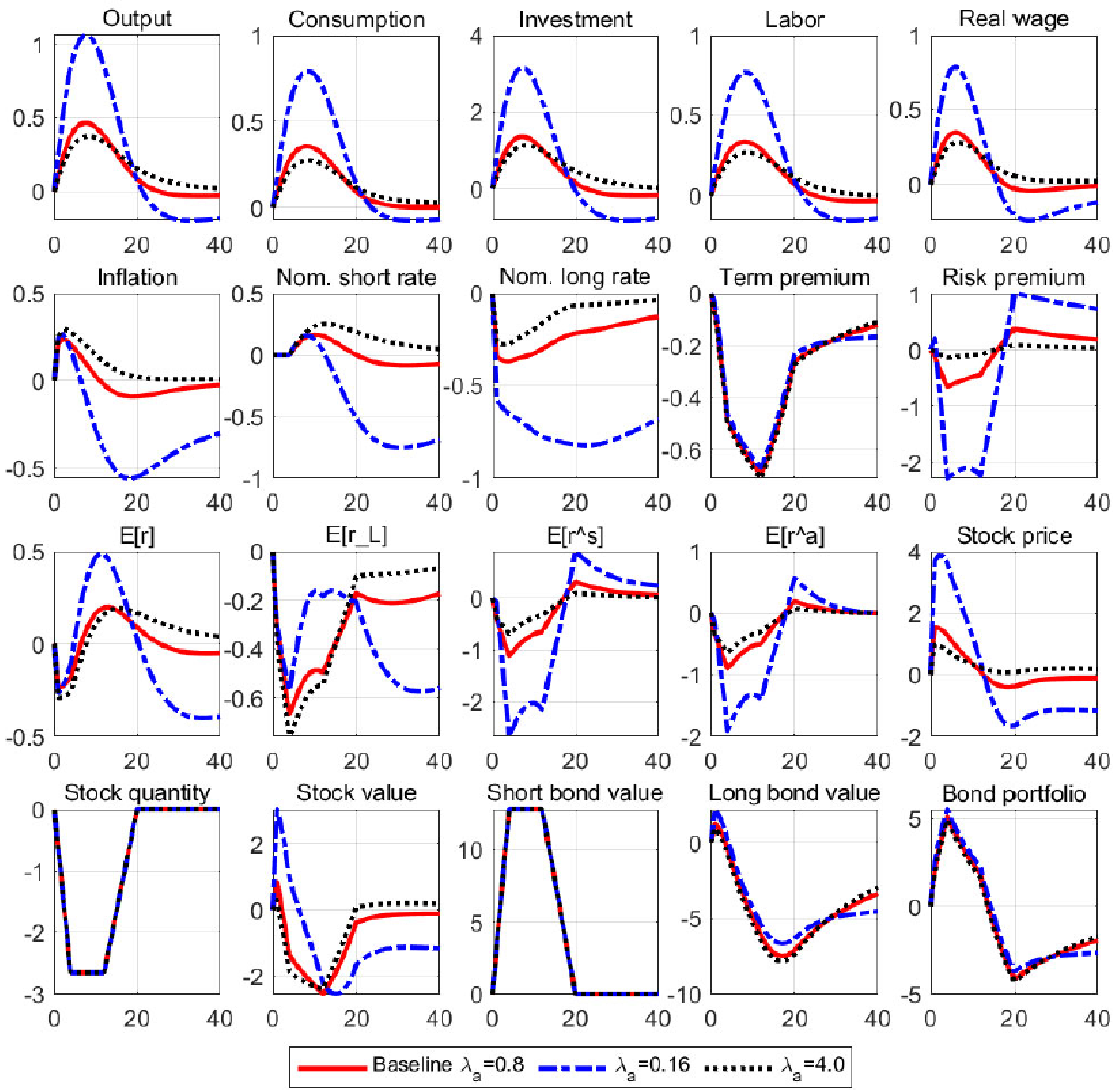

Figure 11: The effects of large-scale stock purchases (in %) under different values for the elasticity of substitution between stocks and bonds, λ_a. Solid red lines depict the baseline results with $\lambda_a = 0.80$.

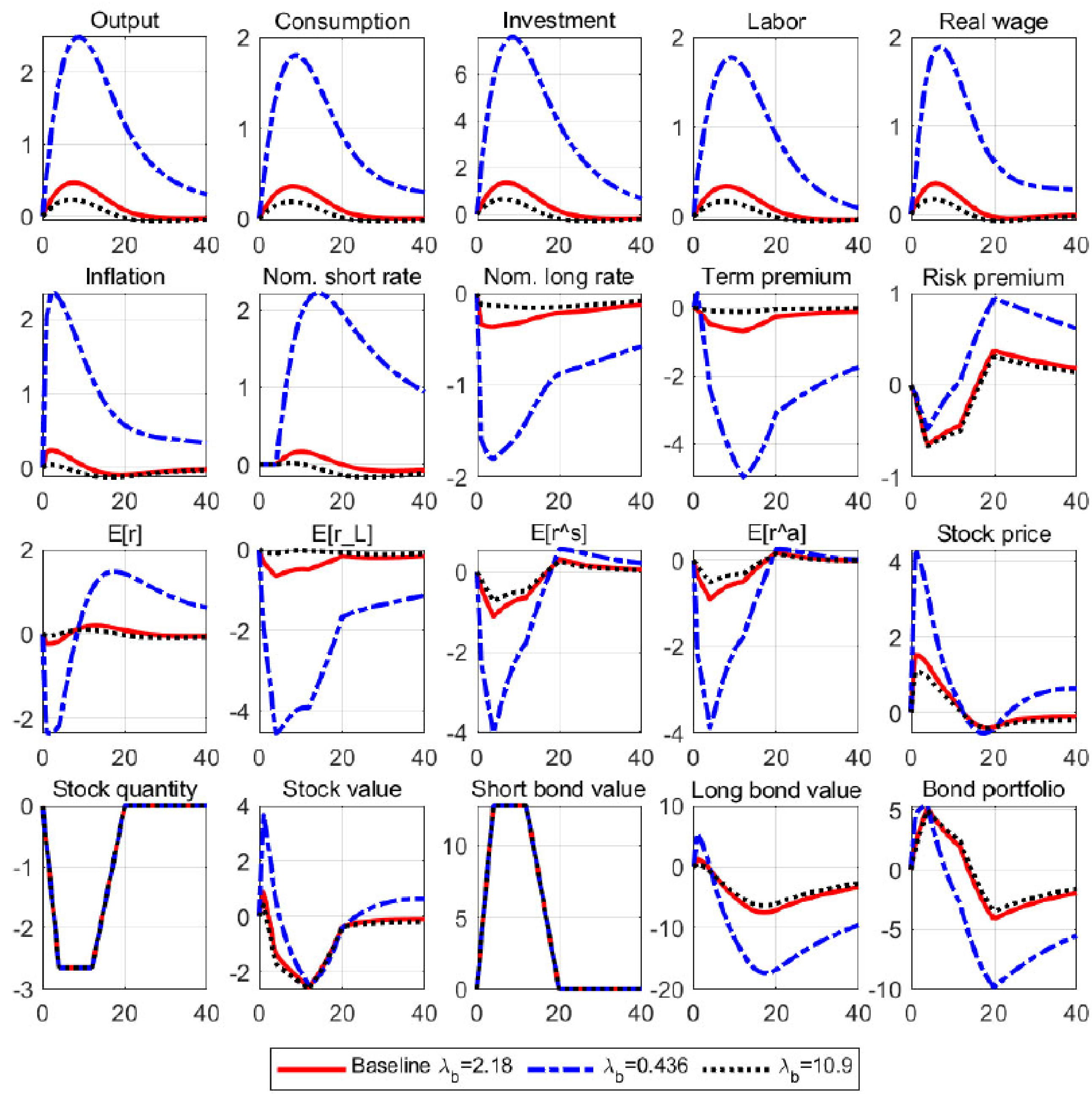

Figure 12: The effects of large-scale stock purchases (in %) under different values for the elasticity of substitution between short- and long-term bonds, λ_b. Solid red lines depict the baseline results with $\lambda_b = 2.18$.