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Does the Way of Financing Quantitative Easing Programmes Matter?

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Abstract

This paper applies a DSGE model to find whether the way of financing QE2 matters for the reaction of the economy. The model includes a segmented bond market structure, thus the large-scale asset purchases may successfully influence the economy. It is shown that the effects on macroeconomic variables are very similar regardless of whether the government finances the purchases by lump-sum taxes or by short-term debt which signifies that the quantitative deviation from Ricardian equivalence introduced by bond market segmentation is insignificant. The redistribution effects caused by financing are noticeable.

Keywords: quantitative easing, unconventional monetary policy, Ricardian equivalence

JEL Classification: E43, E44, E52, E58, E63

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1 Introduction

Short-term nominal interest rate is a standard monetary policy instrument used by central banks. Over the last few years, the federal funds rate (FFR) in the United States as well as policy interest rates in many other countries decreased to zero. After the financial crisis of 2007 the economic conditions were poor and the economy needed more stimulus to revive. Moreover, the reserves kept at the Federal Reserve before the financial crisis increased from around \$10 billion to around \$1 trillion after the crisis (Hamilton and Wu, 2012).

Since FFR reached its zero-lower bound (ZLB) in December 2008, it was impossible to the Federal Reserve to boost the economy by using its key instrument and unconventional monetary policy was needed. The Federal Reserve decided to launch three rounds of so called quantitative easing (QE) programmes.

QE involves purchasing a large amount of assets by the central bank. The aim of the purchases is to stimulate the economic activity when it is poor. The two most important channels through which QE impacts Treasury yields are portfolio balance and signalling channels. They are included in the modelling framework of this paper. Central bank's asset purchases decrease risk premia of securities. It induces the portfolio balance channel which makes investors replace long-term assets with short-term ones. Signalling channel affects investors' beliefs concerning the future policy interest rate. Central bank's announcements of launching the QE programme and keeping the interest rate at the ZLB induce signalling. The Federal Open Market Committee's (FOMC) announcement of QE2 caused the signalling effect which was visible in the market participants' expectation of FFR staying low (e.g. Chen *et al.* 2012 refer to the survey conducted by Blue Chip in which its participants reckon that FFR should stay at the ZLB for the next 4/5 quarters).

The current analysis of QE2 applies a closed-economy dynamic stochastic general equilibrium (DSGE) model. The paper implements segmentation in the bond market where two types of assets are available: short-term and long-term bonds. There are two types of households: restricted and unrestricted. The households have heterogeneous preferences for the assets – restricted households prefer to hold only long-term bonds while unrestricted households prefer to diversify their bond holdings by choosing both short-term and long-term securities. Due to the heterogeneous preferences, short-term and long-term bonds are not perfect substitutes. Unrestricted households have access to both types of assets, however they have to pay transaction costs for each unit of long-term bond to a financial institution for its service. Restricted households may hold only long-term bonds. Therefore, they cannot adjust their portfolios by taking advantage of arbitrage opportunities between short-term and long-term securities when the risk premium changes. Unrestricted agents, however, are allowed to fully arbitrage away, but their arbitrage opportunities are limited by some amount of transaction costs.

The presence of two frictions, market segmentation and transaction costs, has important implications for results. Firstly, it makes the QE programmes work, unlike

in models which include frictionless markets. Hence, the programmes have effects on the economy. Secondly, the heterogeneity between individuals results in breaking the Ricardian equivalence. Consequently, different methods of financing the purchases have different influence on consumption, and thus on aggregate demand.
The aim of the paper is to analyse whether the deviations from Ricardian equivalence are quantitatively significant. If so, policymakers should carefully select the method of financing. On the contrary, if differences are small enough, the form of financing does not matter a lot for stimulating the economy. The second crucial question posed is whether the methods of financing have a significant impact on redistribution between two types of households. This is an important issue in current discussion on policy effects (see for example Borio and Zabai, 2016; Constâncio, 2017). Previous research on the effects of QE mostly focused on the asset side of the central banks' balance sheets, ignoring issues connected with financing the programmes. To the best of the author's knowledge, no literature analysing links between public debt management and unconventional monetary policy in a formal model exists. To fill this literature gap, this paper investigates different forms of financing QE within the DSGE framework proposed by Chen *et al.* 2012.
The main result is that the deviations from Ricardian equivalence introduced by bond market segmentation are not significant. It means that the choice of the method of financing the large-scale asset purchase programmes does not matter for a size of the reaction of the economy. In the baseline simulation, the GDP level is higher by 1.39% when the QE programme is financed fully by bonds than by taxes. On the other hand, the evidence on redistribution effects between allocations is found. In the baseline scenario, agents adjust their consumption level differently for the given ways of financing.
The remainder of this paper is organized as follows. Section 2 reviews the related literature. Section 3 introduces the model and its calibration. Section 4 presents simulations and the main findings. Section 5 analyses the robustness of the baseline results. Section 6 concludes.

2 Literature Review

Quantitative easing (QE) is one of the available monetary policy alternatives when the short-term nominal interest rate cannot be further decreased. Bernanke *et al.* (2004) define QE as a nonstandard policy which leads to changes in the size of the central bank's balance sheet. It works as open-market purchases which increase the supply of the central bank's reserves. When the central bank buys sufficiently large amount of bonds or securities, it provides additional liquidity to the economy. The difference between standard open-market operations and QE is their scale and circumstances under which they are made (Bean, 2010).
However, Hamilton and Wu (2012) notice that when the policy interest rate remains at the ZLB, the open-market purchases of short-term assets against money include

trading in substitutes. This method is inefficient in decreasing the short-term interest rate. Therefore, the success of QE is reflected in changes of the yield curve. The changes which include lowering long-term interest rates are possible due to the changes in the supply of long-term assets.

During QE programmes the Federal Reserve purchased both private and government assets. Chen *et al.* 2012 point that the purchases which started in 2009 were composed of agency debt, mortgage-backed securities and Treasury securities and amounted to $1.75 trillion. Bean (2010) determines the aims of both types. Private assets are bought in order to increase the market liquidity which decreases liquidity premia and through that, it decreases the government bond yields. The objective of purchases of government assets is to raise prices of a vast range of assets. This is determined by the behaviour of investors who want to replace sold assets by new ones. Next sections of this paper analyse the QE2 programme announced on 3 November 2010 within which the Federal Reserve bought only Treasuries.

The mechanism through which QE operates differs from the mechanism of traditional open-market operations. There are two main channels through which QE programmes may influence interest rates: the portfolio-balance channel and the signalling channel (Gagnon *et al.*, 2011; Krishnamurthy and Vissing-Jorgensen, 2011). They are connected to a hypothesis which claims that the long-term interest rate is composed of the term-premium and the so called risk-neutral interest rate, i.e. the average level of short-term rates over the bond maturity (the expectation hypothesis). The term premium accounts for the most important part of the risk premium for Treasuries which were bought by the Federal Reserve in QE2. QE works only under the imperfect asset substitutability which means that different assets are not perceived as substitutes by investors. This implies that some investors replace long-term securities with short-term ones and some are displaced due to the central bank's purchases. The purchases make the asset prices increase and they reduce the yields of these assets. Hence, the risk premium diminishes, encouraging investors to invest in safe short-term securities. The effect of the portfolio adjustment resulting from the change in the risk premium is known as the portfolio-balance effect (Gagnon *et al.*, 2011). The signalling channel affects the second component of the long-term interest rate. It works through lowering the investors' expectations about the level of future short-term rates. Hence, it may extend the length of the expected period of very low interest rates and thus reduce the yields on the bonds (Bauer and Rudebusch, 2014). Krishnamurthy and Vissing-Jorgensen (2011) notice that QE should influence all interest rates of bonds thanks to the expectation hypothesis. The investors' expectations might be affected by the central bank's large-scale asset purchases. The Federal Reserve's QE announcements contain sometimes the discussion of its future short-term interest rates. Krishnamurthy and Vissing-Jorgensen (2011) argue that any non-conventional policy may be perceived as a signal that the central bank would keep the interest rate low for an extended period.

There is no common agreement on the effects caused by the QE programmes. One part

of the existing research finds that the large-scale asset purchases have almost no effect on stimulating the economy whereas the other part finds a significant impact. The QE programmes do not influence the economy in a world without frictions in Eggertsson and Woodford (2003), which is consistent with the findings of Wallace (1981). Since reserves and purchased assets such as short-term government bonds are perceived as perfect substitutes by consumers, the conclusion about no effects is also true for the model with credit frictions by Cúrdia and Woodford (2011). Williamson (2012), Gertler and Karadi (2013, 2011) and Del Negro *et al.* (2017) also focus on frictions in private markets. Greenwood *et al.* (2016) show that there is a need to understand market segmentation in order to well plan and assess effects of QE programmes. Andrés et al. (2004) propose a model which captures imperfect asset substitutability. Their framework is used by Chen *et al.* (2012) to study the effects of QE. They find that the programmes have effects similar to a sudden 25 bp decline in the FFR. The existing extensive empirical literature concerning the effects of QE finds usually bigger effects. The decline in long-term interest rate usually amounts to between 15 to 90 bp among different QE programmes and using different methodology (see for example Swanson, 2011; Krishnamurthy and Vissing-Jorgensen, 2011; D'Amico and King, 2013; D'Amico *et al.*, 2012; Gagnon *et al.*, 2011; Hamilton and Wu, 2012).
An important issue which is usually omitted when talking about QE is its connection with fiscal policy and public debt management (PDM). The links between monetary policy and PDM are pointed by Turner (2011) and Blommestein and Turner (2012). Both policies involve the sale of debt, either by the Federal Reserve or by the Treasury, to the private sector. It makes the two policies hard to separate. In particular, this feature influences portfolio choice because investors perceive the issuance of short-term government bonds as monetary expansion. A decline in asset substitutability increases the effectiveness of balance sheet policies such as QE and decreases the effectiveness of conventional monetary policy. This brings QE closer to fiscal policy and PDM. However, the effectiveness of QE depends on PDM because the fiscal authority can act against the central bank's QE programmes by lengthening the average maturity of its outstanding debt. The similarities between unconventional monetary policy and fiscal policy are also underlined by Borio and Zabai (2016). They argue that central bank's balance sheet policies can be replaced by similar actions undertaken by the government. In such a case, the central bank's balance sheet should be considered as part of the consolidated government sector balance sheet.

3 Model

The model described in this paper follows the model by Chen *et al.* (2012) which uses the segmented market structure of Andrés *et al.* (2004). There are two types of households: unrestricted who may trade in short-term and long-term bonds and restricted who can only trade in long-term bonds. They provide labour inputs which are combined into a homogeneous labour composite. Three types of producers operate in the economy: competitive capital and final goods producers and monopolistically competitive intermediate goods producers. Monetary and fiscal policy is set by the government. The full set of log-linearised equations can be found in the appendix.

3.1 Households

There is a continuum of households indexed by $i \in [0,1]$. A household may be of type $j \in \{u, r\}$, where u denotes an unrestricted household and r denotes a restricted one. Utility of households is derived from consumption C_t^j divided by the productivity level Z_t. It is reduced by the number of hours a household works L_t^j. The CRRA utility function is augmented by assuming external habit formation. Households perfectly share consumption risk and maximise their life-time utility

$$\mathbb{E}_t \sum_{s=0}^{\infty} \beta_j^s b_{t+s}^j \left\{ \frac{1}{1-\sigma_j} \left(\frac{C_{t+s}^j}{Z_{t+s}} - h \frac{C_{t+s-1}^j}{Z_{t+s-1}} \right)^{1-\sigma_j} - \frac{\varphi_{t+s}^j [L_{t+s}^j(i)]^{1+\nu}}{1+\nu} \right\}, \tag{1}$$

where $\beta_j \in (0,1)$ is the discount factor of type j, σ_j is the coefficient of relative risk aversion, $h \in (0,1)$ is the habit forming parameter, ν is the inverse of Frisch elasticity of labour, b_t^j and φ_t^j are shocks in time preferences and in disutility of labour respectively following AR(1) processes.
We denote by ω_u the fraction of unconstrained households and by $\omega_r = 1 - \omega_u$ the fraction of constrained households. The bond market is modelled in a way to allow for imperfect asset substitutability. Therefore, short-term and long-term securities are not perceived as the same asset by economic agents. Both types of households are allowed to invest in long-term bonds $B_t^{L,j}$. However, unrestricted households need to pay time-varying transaction cost $1 + \zeta_t$. These households invest in long-term bonds for diversification and the cost they pay is transferred to financial institutions which are intermediaries in the bond market. Restricted households may be perceived as part of population which mostly saves through pension funds which have negligible transaction costs. Short-term bonds B_t can be bought only by the fraction of unrestricted households.
The budget constraint of a household depends on its type. It is given by

$$\begin{aligned} P_t C_t^u + B_t^u + (1+\zeta_t) P_{L,t} B_t^{L,u} \leq R_{t-1} B_{t-1}^u + \sum_{s=1}^{\infty} \kappa^{s-1} B_{t-s}^{L,u} + W_t^u(i) L_t^u(i) + \\ + \mathcal{P}_t + \mathcal{P}_t^{cp} + \mathcal{P}_t^{fi} - T_t^u \end{aligned} \tag{2}$$

if the household is unrestricted or by

$$P_t C_t^r + P_{L,t} B_t^{L,r} \leq \sum_{s=1}^{\infty} \kappa^{s-1} B_{t-s}^{L,r} + W_t^r(i) L_t^r(i) + \mathcal{P}_t + \mathcal{P}_t^{cp} + \mathcal{P}_t^{fi} - T_t^r \tag{3}$$

if it is restricted. Here, P_t denotes the price of the consumption good, $P_{L,t}$ is the price of the long-term bond, R_t is the short-term interest rate, $\kappa \in (0,1]$ is the coupon paid by long-term securities, W_t^j is the wage received by a jth household, $\mathcal{P}_t$ and $\mathcal{P}_t^{cp}$ are profits that households receive if they own intermediate or capital producers respectively, $\mathcal{P}_t^{fi}$ are dividends paid by financial institutions to all shareholders who are households of both types and T_t^j are lump-sum taxes paid by ith household.
The demand for labour supplied by ith household

$$L_t(i) = \left[\frac{W_t(i)}{W_t}\right]^{-(1+\lambda_w)/\lambda_w} L_t \tag{4}$$

is derived from solving the profit maximisation problem. Here, $L_t = \left[\int_0^1 L_t(i)^{1/(1+\lambda_w)} di\right]^{1+\lambda_w}$ and $W_t = \left[\int_0^1 W_t(i)^{-1/\lambda_w} di\right]^{-\lambda_w}$. Unlike in Chen *et al.* (2012), it is assumed that the wages are perfectly flexible.

3.2 Capital Producers

Capital producers are perfectly competitive. They make investment decisions. These firms rent capital to intermediate goods producers and decide on the level of rented capital (effective capital) K_t by choosing the utilization rate u_t

$$K_t = u_t \bar{K}_{t-1},$$

where $\bar{K}_t$ is the newly-produced capital.
The problem of firms which rent capital is to maximise

$$\mathbb{E}_t \sum_{s=0}^{\infty} \Xi_{t+s}^p \left[R_{t+s}^k u_{t+s} \bar{K}_{t+s-1} - P_{t+s} a(u_{t+s}) \bar{K}_{t+s-1} - P_{t+s} I_{t+s}\right],$$

where $\Xi_t^p \equiv \omega_u \beta_u^s \Xi_t^{u,p} + \omega_r \beta_r^s \Xi_t^{r,p}$ is the marginal utility of the average shareholder, R_t^k is the rental rate which determines the return on investing one unit of effective capital and P_t is the price of the consumption good. Function $a(u_t)$ reflects the cost related to higher utilization of capital.
Capital producers buy final investment good I_t and undepreciated capital from previous period $(1-\delta)\bar{K}_{t-1}$ each period. They are constrained by the capital accumulation equation

$$\bar{K}_t = (1-\delta)\bar{K}_{t-1} + \mu_t \left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right] I_t, \tag{5}$$

where $\delta \in (0,1)$ is the depreciation rate, μ_t is a shock specific to investment goods productivity following an AR(1) process and $S(\cdot)$ is the investment adjustment cost whose derivatives are $S'(\cdot) \geq 0$ and $S''(\cdot) > 0$.

3.3 Final Goods Producers

Final goods producers of unit mass are perfectly competitive. They maximise profits subject to the equation for the final good Y_t which they produce by combining goods $Y_t(i)$ bought from intermediate goods producers for price $P_t(i)$. By solving the problem

$$\max_{Y_t, Y_t(i)} \quad P_t Y_t - \int_0^1 P_t(i) Y_t(i) di$$
$$\text{s.t.} \qquad Y_t = \left[\int_0^1 Y_t(i)^{1/(1+\lambda_f)} di \right]^{1+\lambda_f},$$

where $\lambda_f > 0$ is the steady-state price markup, we obtain the demand funtion for the intermediate goods

$$Y_t(i) = \left[\frac{P_t(i)}{P_t} \right]^{-(1+\lambda_f)/\lambda_f} Y_t, \tag{6}$$

where $P_t = \left[\int_0^1 P_t(i)^{-1/\lambda_f} df \right]^{-\lambda_f}$ is the aggregate price index obtained from the zero-profit condition.

3.4 Intermediate Goods Producers

Unlike previous two producers, firms which produce intermediate goods operate in a monopolistic competitive environment. The intermediate good is created by combining capital K_t and labour L_t according to the technology

$$Y_t(i) = K_t(i)^\alpha [Z_t L_t(i)]^{1-\alpha}, \tag{7}$$

where Z_t is the productivity. We define the growth rate of productivity $z_t = \ln(e^{-\gamma} Z_t / Z_{t-1})$ which follows an AR(1) process.
With the probability of $1 - \zeta_p$ intermediate goods producers are allowed to reset their prices on the basis of the Calvo (1983) scheme. Then, they maximise

$$\mathbb{E}_t \sum_{s=0}^{\infty} \zeta_p^s \Xi_{t+s}^p [\tilde{P}_t(i) \Pi^s - \lambda_{f,t+s} MC_{t+s}] Y_{t+s}(i)$$

subject to the demand function from (6) and where the marginal cost MC_t, derived from cost minimization subject to the production function in equation (7), is equal for each firm

$$MC_t(i) = MC_t = \frac{\left(R_t^k\right)^\alpha W_t^{1-\alpha}}{\alpha^\alpha (1-\alpha)^{1-\alpha} Z_t^{1-\alpha}}. \tag{8}$$

Here, $\tilde{P}_t$ is the new price, Π is the steady-state inflation rate, $\lambda_{f,t}$ is a time-varying price markup following an AR(1) process. The fraction of firms which are not allowed to reoptimize their prices adjust the old prices with respect to the steady-state inflation rate.

3.5 Government

The actions undertaken by monetary and fiscal authorities are considered as one policy. As argued in section 2, imperfect asset substitutability makes these two policies similar. Especially, it is assumed that short-term debt is composed of short-term government bonds and central bank's reserves.
The central bank sets a monetary policy rule in the spirit of Taylor (1993) given by

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_m} \left[\left(\frac{\Pi_t}{\Pi}\right)^{\phi_\pi} \left(\frac{Y_t/Y_{t-4}}{e^{4\gamma}}\right)^{\phi_y}\right]^{1-\rho_m} e^{\epsilon_{m,t}}.$$

The parameters in the rule are $\phi_\pi > 1$, $\phi_y \geq 0$ and the smoothing parameter is $\rho_m \in (0,1)$, $\Pi_t \equiv \frac{P_t}{P_{t-1}}$ is the inflation rate and $\epsilon_{m,t}$ is an i.i.d. monetary policy shock.
Since long-term bonds are included in the model, they are an additional element to the standard government budget constraint. Therefore, the government issues short-term and long-term debt which is paid off the next period. These bonds and lump-sum taxes T_t finance government purchases G_t:

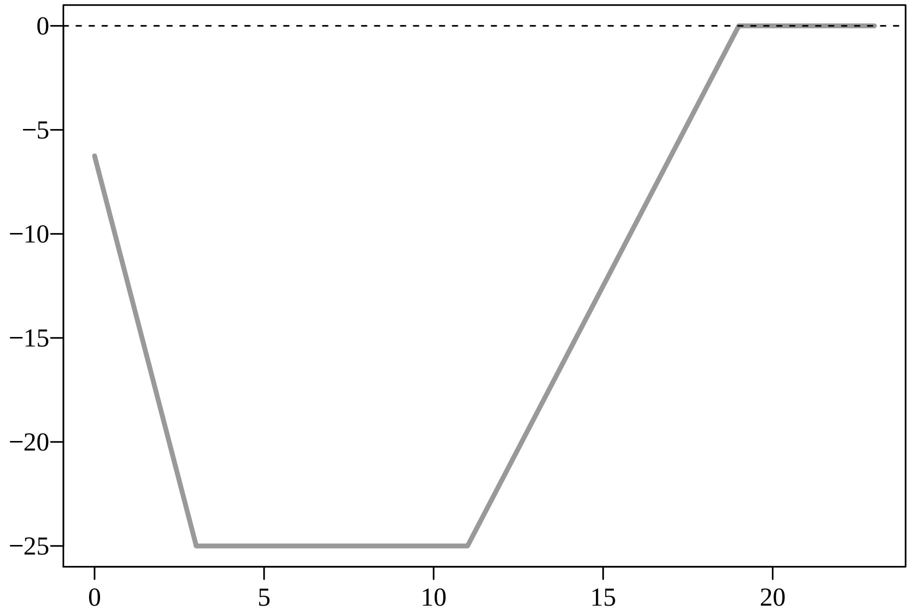
$$B_t + P_{L,t}B_t^L = R_{t-1,t}B_{t-1} + (1+\kappa P_{L,t})B_{t-1}^L + P_tG_t - T_t. \tag{9}$$

Methods of financing the central bank's purchases by the government are analysed in subsequent parts of the paper. The variables which may be used to finance QE as well as the debt composition are further treated exogenously.
The QE operations are introduced into the model as a series of shocks $\epsilon_{B,t}$ (compare with equation 42 without QE):

$$-\frac{R_L}{R_L-\kappa} r_{L,t} + \hat{B}_{z,t}^L = \epsilon_{B,t}, \tag{10}$$

where R_L is the steady-state long-term yield. The path of the shock is handled deterministically for 24 quarters in a way to directly influence the log-linearised market value of long-term debt (left-hand side of equation 10). The precise path of the change in market value of debt in each period of QE is presented in Figure 1. The exact description of log-linearised variables is provided in the appendix.
In order to strengthen QE effects, the central bank keeps the policy interest rate at the ZLB (ZLB commitment thereafter) for the first 4 quarters of the purchases. Therefore, it is assumed that the short-term interest rate is kept at the constant steady-state level, thus mimicking the ZLB, $r_t \equiv \ln(R_t/R) = 0$ for $t \in \{0,1,2,3\}$ (compare with equation 44 without the ZLB commitment).

Figure 1: Simulated Path of the Market Value of Long-term Bonds (%)



Notes: The path in the figure corresponds to the path proposed by Chen *et al.* (2012).

3.6 Exogenous Processes

The shocks evolve according to the processes described below.

Productivity shock defined as $z_t = \ln\left(e^{-\gamma} Z_t / Z_{t-1}\right)$ follows: $z_t = \rho_z z_{t-1} + \epsilon_{z,t}$.

Labour supply shock follows: $\ln \varphi_t = \rho_\varphi \ln \varphi_{t-1} + \epsilon_{\varphi,t}$.

Investment shock follows: $\ln \mu_t = \rho_\mu \ln \mu_{t-1} + \epsilon_{\mu,t}$.

Preference shock follows: $\ln b_t = \rho_b \ln b_{t-1} + \epsilon_{b,t}$.

Government spending shock follows: $\ln g_t = \rho_g \ln g_{t-1} + \epsilon_{g,t}$.

Risk premium shock follows: $\epsilon_{\zeta,t} = \rho_\zeta \epsilon_{\zeta,t-1} + \eta_{\zeta,t}$.

Price markup shock follows: $\ln \lambda_{f,t} = \epsilon_{\lambda,t}$.

Monetary policy shock $\epsilon_{m,t}$, fiscal policy shock $\epsilon_{T,t}$ and long-term bond supply shock $\epsilon_{B,t}$ are white noises.

For variable x_t, the autocorrelation parameter $\rho_x \in (0,1)$ and $\epsilon_{x,t} \sim N(0, \sigma_x^2)$, where σ_x denotes a standard deviation of the innovation.

3.7 Equilibrium

Households and firms solve their maximisation problems subject to the relevant constraints described in earlier sections. Resource constraint is derived from combining the budget constraints of unrestricted and restricted households as well as the budget constraint of the government. It is given by:

$$Y_t = \omega_u C_t^u + \omega_r C_t^r + I_t + G_t + a(u_t)\bar{K}_{t-1}.$$

3.8 Transaction Costs and Risk Premium

Similarly to Chen *et al.* (2012), it is assumed that transaction costs are a function of the market value of long-term debt. However, since only unrestricted households pay transaction costs $(1+\zeta_t)$, the long-tem bonds consist of ones held by unrestricted households only:

$$1 + \zeta_t \equiv \zeta\left(P_{L,t}B_{z,t}^{L,u}, \epsilon_{\zeta,t}\right), \tag{11}$$

where $B_{z,t}^{L,u} \equiv B_t^{L,u}/(P_t Z_t)$ and $\epsilon_{\zeta,t}$ is a risk premium shock following an AR(1) process. The transaction costs function and its derivative need to meet the following conditions in steady state, however no particular form of function $\zeta(\cdot)$ is required: $\zeta(P_{L,t}B_z^{L,u}, 0) > 0$, which guarantees that the steady-state risk premium is positive, and $\zeta'(P_{L,t}B_z^{L,u}, 0) > 0$, which makes the long-term yield decrease when the market value of debt shrinks. These conditions ensure that QE influences the economy. Since the central bank's purchases reduce the size of the market value of debt and reduce the long-term yield, the restricted households have to change their consumption-savings decisions, thus influencing GDP and inflation. It is possible due to heterogeneity, which ensures that the restricted agents have an access only to long-term bonds and cannot adjust their investments by short-term bonds.

The stated formulation of transaction costs captures two frictions in the bond market described by Andrés *et al.* (2004). Firstly, instead of paying 1, unrestricted households pay time-varying transaction costs $(1+\zeta_t)$. Secondly, the households perceive holding long-term bonds as riskier than the short-term ones, which is reflected by liquidity costs expressed by an additional cost function. The current assumption about the transaction costs depending on the market value of debt can be viewed as equivalent to the second friction.

The Euler equations derived from households optimisation problems are interpreted as pricing equations for short-term and long-term securities, emphasizing the role of asset market segmentation.

Keeping in mind that only unrestricted households may trade in short-term bonds, the Euler equation for them is

$$1 = \beta_u \mathbb{E}_t\left(e^{-\gamma - z_{t+1}} \frac{\Xi_{t+1}^u}{\Xi_t^u} \frac{R_t}{\Pi_{t+1}}\right). \tag{12}$$

On the other hand, long-term securities may be purchased by both types of households. The pricing equation for long-term bonds for unrestricted households is

$$1+\zeta_t = \beta_u \mathbb{E}_t \left(e^{-\gamma - z_{t+1}} \frac{\Xi^u_{t+1}}{\Xi^u_t} \frac{P_{L,t+1}}{P_{L,t}} \frac{R_{L,t+1}}{\Pi_{t+1}} \right), \tag{13}$$

while the equation for restricted households does not include transaction costs:

$$1 = \beta_r \mathbb{E}_t \left(e^{-\gamma - z_{t+1}} \frac{\Xi^r_{t+1}}{\Xi^r_t} \frac{P_{L,t+1}}{P_{L,t}} \frac{R_{L,t+1}}{\Pi_{t+1}} \right). \tag{14}$$

Here, Ξ^j_t denotes the marginal utility of consumption of the household of type $j = u, r$ and $e^{-\gamma - z_{t+1}}$ is the determinant of productivity growth.
The transaction costs characterised above are crucial for a risk premium. Using the Euler equation for long-term debt of unrestricted households (13), one can derive the Euler equation under the assumption of no financial frictions:

$$1 = \beta_u \mathbb{E}_t \left(\frac{\Xi^{u,p}_{t+1}}{\Xi^{u,p}_t} \frac{P^c_{L,t+1}}{P^c_{L,t}} R^c_{L,t+1} \right), \tag{15}$$

where $\Xi^{u,p}_t$ denotes the marginal utility of consumption of the unrestricted household in nominal terms, $P^c_{L,t}$ and $R^c_{L,t}$ are counterfactual long-term price and long-term yields respectively. This equation is not affected by the transaction-cost friction. By writing equation (13) in nominal terms and subtracting equation (15), one obtains:

$$\mathbb{E}_t \left[\frac{\Xi^{u,p}_{t+1}}{\Xi^{u,p}_t} \left(\frac{P_{L,t+1}}{(1+\zeta_t) P_{L,t}} R_{L,t+1} - \frac{P^c_{L,t+1}}{P^c_{L,t}} R^c_{L,t+1} \right) \right] = 0. \tag{16}$$

The risk premium $\hat{RP}_t$ is defined as the difference between the long-term yield $\hat{R}_{L,t}$ and the counterfactual long-term yield $\hat{R}^c_{L,t}$. In a first order log-linear approximation equation (16) may be transformed to

$$\hat{RP}_t \equiv \hat{R}_{L,t} - \hat{R}^c_{L,t} = \frac{1}{D_L} \sum_{s=0}^{\infty} \left(\frac{D_L - 1}{D_L} \right)^s \mathbb{E}_t \hat{\zeta}_{t+s} \tag{17}$$

which is the definition of the risk premium. Here, variables with hats denote log deviations from steady state and $D_L = R_L/(R_L - \kappa)$ is duration of the long-term bond. Equation (17) indicates that the risk premium depends on the current and discounted at period 0 transaction costs. The rise in transaction costs results in the increase in risk premium. Therefore, similarly to the change in transaction costs, the change in risk premium will also have real effects on the economy.

3.9 Calibration

The parameters are set to correspond to the values of the posterior mean by Chen *et al.* (2012). They apply Bayesian methods in their estimation. The Bayesian approach to obtain the posterior distribution consists of connecting prior information to the likelihood function. They create the function using the Kalman filter. The Gamma distribution is used regarding the parameters that should be positive according to economic theory, whereas the Beta distribution is used if parameters are included between the unit interval. The posterior distribution is obtained by deriving the posterior mode, a normal approximation around it and using the Markov Chain Monte Carlo (MCMC) method. Parameters that have not been estimated include the ones which are standard in the literature. The data used in the estimation comes from the Federal Reserve Economic Data (FRED). The sample includes quarterly data from the third quarter of 1987 to the third quarter of 2009 for the US economy.

Government spending $G_z = 0.194$ is calibrated as the average share of government consumption expenditures and gross investment in GDP from the third quarter of 1987 to the third quarter of 2009 (it corresponds to the period used in the estimation by Chen *et al.* 2012) from FRED. The share of capital in GDP α is set to 0.33 and the depreciation rate of capital δ to 2.5% per quarter. Both short-term and long-term debts are calibrated to account for 16% of annual GDP, which is the average in the US since 1974. Price markup λ_p is set to 20%. Duration D_L is set to 30 quarters which is comparable to the average duration of US 10-year Treasuries in the secondary market. Coupon is a function of the yield and duration of long-term bonds: $\kappa = R_L - R_L/D_L$. Table 1 presents the posterior means of all parameters estimated by Chen *et al.* (2012).

The prior of annual inflation is set to 2% coinciding with the inflation target of the FOMC and implying the posterior mean of 2.15%. Gross inflation rate is defined as $\Pi = 1 + \pi$. The prior of annual growth rate is 2% implying the posterior mean of 1.99%. The discount factor of unrestricted households is set to 0.995 implying an annual real interest rate of 2% and the posterior mean of about 0.999 implying the real interest rate of 0.48%.

The prior for fraction of unrestricted households ω_u is set to 70% while the posterior mean is 93.22%. The discrepancy between the two values is significant. The parameter is crucial to results since it governs the market segmentation friction. Hence, the robustness of results presented in the next section will be tested for the change in this parameter.

The second parameter responsible for the friction is elasticity of the risk premium ζ'. Since the parameter influences the transaction costs, it determines the change in risk premium when the central bank purchases the long-term assets. Its prior amounts to 1.5/100 while the posterior mean is 0.376/100. The estimate close to zero implies insignificant influence of the purchases on the reduction in risk premium and long-term yield.

Moreover, it is assumed that: $Y_z = 1$, $S(e^{\gamma}) = S'(e^{\gamma}) = 0$, $a(u_t)$ is such that in steady

Table 1: Calibration of Structural Parameters

Parameter	Value	Description
400γ	1.9867	Steady-state growth rate
400π	2.1477	Steady-state inflation
$400\left(\beta_u^{-1}-1\right)$	0.4890	Discount factor of unrestricted households
400ζ	0.5127	Steady-state spread
B^{LMV}/B	0.8502	Steady-state ratio of market value of long-term debt to short term debt
S''	4.8371	Investment adjustment cost convexity parameter
a''	0.2322	Utilisation cost elasticity
h	0.7898	Habit formation
σ_u	3.4958	Inverse of intertemporal elasticity of substitution of unrestricted households
σ_r	2.2370	Inverse of intertemporal elasticity of substitution of restricted households
$100\zeta'$	0.3763	Elasticity of the risk premium
ω_u	0.9322	Fraction of unrestricted households
Ξ^u/Ξ^r	1.1403	Stady-state ratio of marginal rates of substitution
C^u/C^r	1.0533	Stady-state ratio of consumption
ν	1.9658	Inverse of Frisch labour supply elasticity
ζ_p	0.9287	Price rigidity
ϕ_T	1.3147	Fiscal rule parameter
ρ_m	0.8556	Interest rate smoothing
ϕ_π	1.6090	Response to inflation
ϕ_y	0.3295	Response to output growth

Notes: The table contains parameters estimated by Chen *et al.* (2012).

state $u = 1$ and $a(1) = 0$. The remaining parameters are derived from steady-state relations within the model equations. They are listed below.

Discount factor of restricted households: $\beta_r = \beta_u/(1+\zeta)$

Average discount factor: $\bar{\beta} = (\omega_u\Xi^u/\Xi^r\beta_u + \omega_r\beta_r)/(\omega_u\Xi^u/\Xi^r + \omega_r)$

Return on capital: $r^k = 1/\bar{\beta}e^\gamma - (1-\delta)$

$\chi_{pu} \equiv \omega_u/\left[\omega_u + \omega_r(1-\beta_u\zeta_p)/(1-\beta_r\zeta_p)(\Xi^u/\Xi^r)^{-1}\right]$

$q_u \equiv \omega_u\Xi^u/(\omega_u\Xi^u + \omega_r\Xi^r) = (\bar{\beta}/\beta_r - 1)\zeta^{-1}$

Short-term yield: $R = \beta_u^{-1}e^\gamma\Pi$

Long-term yield: $R_L = (1+\zeta)R$

Price of long-term bonds: $P_L = 1/(R_L - \kappa)$

Taxes: $T_z = G_z - (1-\beta_u^{-1})B_z - \left[(R_L-\kappa)^{-1} - R_L/(R_L-\kappa)(e^\gamma\Pi)^{-1}\right]B_z^L$

Lagrange multiplier from capital producers' problem: $q = 1$

$\tilde{K}_z \equiv \alpha/(1+\lambda_f)$

Capital: $\bar{K}_z = e^{\gamma}\tilde{K}_z/r^k$

Investment: $I_z = [e^{\gamma} - (1-\delta)]\tilde{K}_z/r^k$

Consumption of restricted households: $C_z^r = (1 - I_z - G_z)/(\omega_u C^u/C^r + \omega_r)$

Consumption of unrestricted households: $C_z^u = C^u/C^r C_z^r$

Wage: $w_z = (1+\lambda_f)^{-1/(1-\alpha)}\alpha^{\alpha/(1-\alpha)}(1-\alpha)(r^k)^{-\alpha/(1-\alpha)}$

Effective capital: $K_z = \tilde{K}_z(r^k)^{-1}$

Labour: $L = K_z^{-\alpha/(1-\alpha)}$

Labour, long-term bonds and taxes are redistributed proportionally among unrestricted and restricted households: $L^r = L$, $L^u = L$, $B_z^{L,r} = B_z^L$, $B_z^{L,u} = B_z^{L,r}$ and $T_z^r = T_z$.

4 Simulations

The intent of this section is to present reactions of selected macroeconomic variables to the QE operations. Especially, it focuses on the effects of two various methods of financing the central bank's purchases. Furthermore, it gives an evidence on significant redistribution effects caused by the programmes.

4.1 Simulation Path

Since QE is announced and the households who hold the long-term bonds know the whole path of the purchases, the simulations are made with a perfect foresight assumption. The QE operations last for 24 quarters and the ZLB binds FFR for the first 4 quarters. During the first 4 quarters the central bank purchases the long-term bonds, during the next 8 quarters it hold its balance sheet unchanged, it gradually sells its long-term bonds for the next 8 quarters and finally it keeps the balance sheet unchanged to the end of the simulation. The whole path is shown in Figure 1. It is expressed as a per cent deviation from trend.

The amount of assets purchased by the central bank is calibrated in a way to correspond to the reduction of $600 billion in long-term bonds held by the private sector. This amount coincides with the amount of Treasuries bought during QE2 and it was revealed in the FOMC announcement of 3 November 2010 (Chen *et al.* 2012). The way of introducing QE and ZLB into the model is presented in section 3.5.

4.2 Baseline Simulation

The focus of the baseline simulation is on the comparison of effects of different forms of financing QE. Equation (9) shows that the government may finance present purchases in two ways: either by issuing debt or by collecting taxes.

In the simulations, two scenarios of financing are checked:

(1) the purchases of long-term bonds are financed fully by short-term debt, i.e. $\hat{T}_{z,t} = 0 \ \forall_t$ or

(2) the purchases are financed fully by taxes, i.e. $\hat{B}_{z,t} = 0 \ \forall_t$.

It is assumed that taxes are redistributed proportionally among households – the restricted agents pay the same taxes per capita as unrestricted ones. The methods of financing may reveal the deviations from Ricardian equivalence and underline the role of coordination between fiscal and monetary authorities concerning PDM, taxation and unconventional monetary policy during the period of imperfect asset substitutability.

The baseline simulation is performed assuming the parameters shown in section 3.9. They are derived from the posterior distribution estimated on the basis of the prior information by Chen *et al.* (2012).

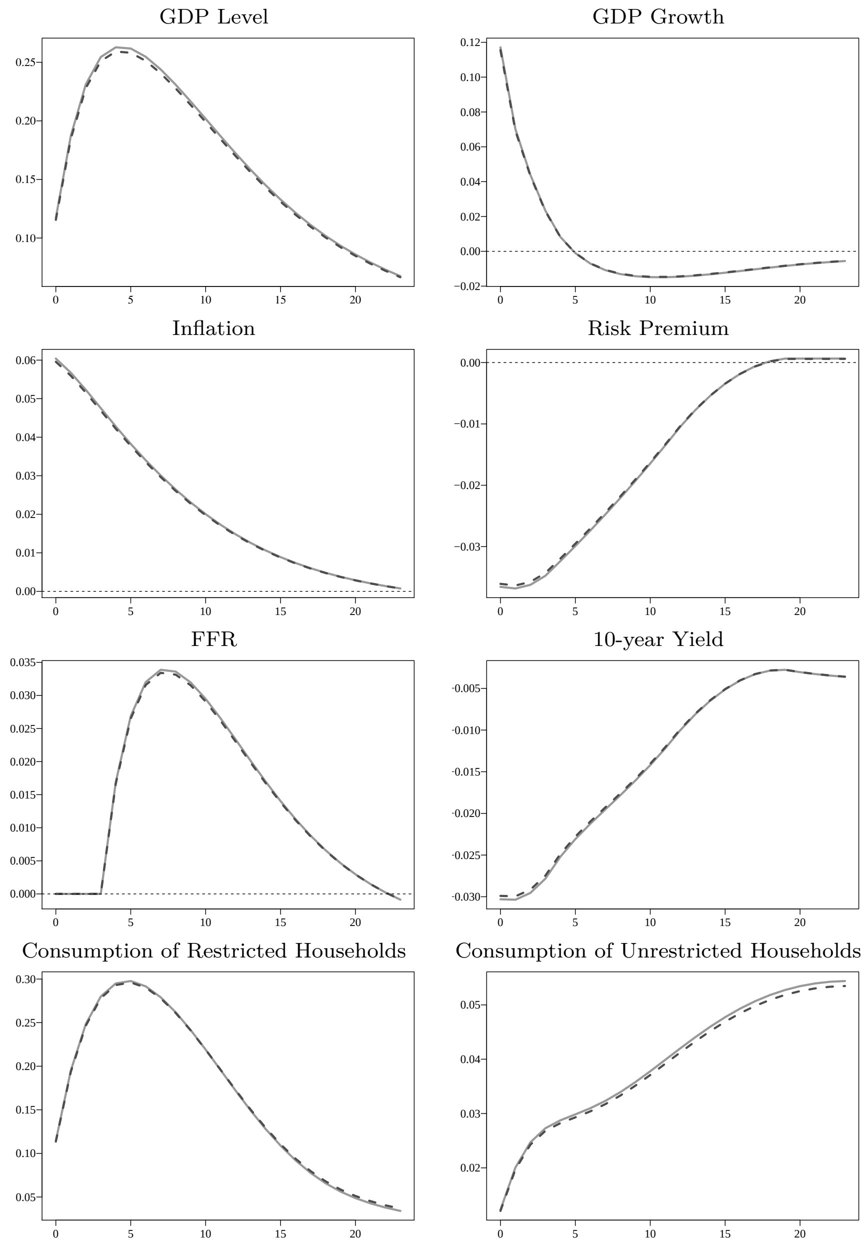
Figure 2 illustrates the response of GDP level, GDP growth rate, inflation, risk premium, short-term interest rate, long-term yield and consumption of restricted and unrestricted households to the asset purchase programme. The presented responses to QE include the whole period of purchases assuming the path of the purchases shown in Figure 1. The solid line shows the simulation under debt financing (scenario 1 listed above) and the dashed line – under tax financing (scenario 2 listed above).

In the simulations, QE works as follows. The central bank's asset purchases are reflected in the decline in market value of long-term debt (Figure 1). This influences the risk premium. Decreasing risk premium boosts aggregate activity which involves the increase in consumption, GDP level and GDP growth as well as it raises inflation. The central bank responds to higher GDP and inflation by increasing the short-term interest rate after 4 quarters of the ZLB commitment. Finally, the reaction of the long-term interest rate depends on the changes in risk premium and short-term interest rate (expectation hypothesis).

At the moment of implementing the QE programme, GDP increases by about 0.12% in both scenarios of financing and reaches its peak of about 0.26% after 4 quarters. The effect of the purchases is noticeable even at the end of the simulation period where the GDP level is 0.07% higher compared to the level without QE. Output growth rises by about 0.12% on impact, then gradually falls and disappears after 4 quarters.

Inflation increases by 6 annualised bp on impact and continuously diminishes thereafter. Its response to the purchases is small but persistent. The central bank forces the FFR to remain at the zero level during the first 4 quarters. Next, the FFR increases and reaches the maximum of about 0.03% after 7 quarters after the beginning of QE.

Figure 2: Reactions of Variables to QE (%)



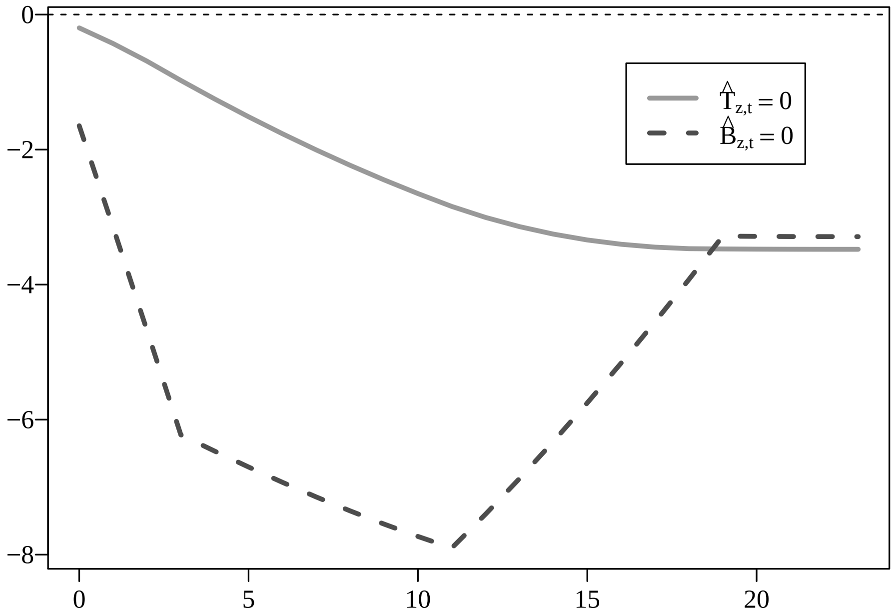
The reaction of the 10-year yield is almost the same as of the risk premium. They decrease on impact and then gradually increase. As suggested by Chen *et al.* (2012), it is due to the poor FFR increase which causes that the expectation hypothesis does not significantly influence the long-term yield. However, the long-term rate remains 0.3 bp below the rate without QE at the end of the simulation period.

The pattern of the reaction of consumption is different for different types of agents. Therefore, QE has significant effects on redistribution of allocations. The increase in consumption of restricted households is 0.1 pp stronger compared to the consumption level of unrestricted households. On the other hand, consumption of unrestricted consumers regularly grows during the whole simulation period whereas consumption of restricted households reaches its peak of 0.3% after 5 periods. The purchases have a persistent effect on the consumption level of unrestricted households, which is not true for consumption of restricted ones. The observation that agents react differently to the asset purchases brings important implications for the evaluation of policy effects and is analysed further in section 5.4.

The results in this section imply that the reaction of the economy to QE does not depend much on how the government chooses to finance the programme. The deviations from Ricardian equivalence introduced by bond market segmentation are not significant. Restricted households want to retain similar level of consumption in both cases of financing. Although they cannot trade in short-term bonds, they are able to adjust their consumption by using long-term ones. When the government finances QE by debt, the adjustments in bond holdings made by restricted agents are gradual. However, in the case of tax financing the budget constraint of the households is influenced directly. The households prefer to make even very sharp modifications in their bond holdings in order to maintain the desired consumption (Figure 3). As a result, they behave almost in the same way as the Ricardian equivalence theorem suggests (e.g. Barro (1989) shows that the government's financial decisions, either to issue budget deficits or to use current taxes, have no influence on investment, and thus on consumption plans, and on aggregate demand). The quantitative assessment of this finding is reviewed in section 5.4. The lack of significant deviations caused by bond and tax financing for the reaction of the economy suggests that the unconventional monetary operations undertaken by the central bank cannot be offset by the decisions on financing. This finding may result from a quite small fraction of households who are not allowed to trade in short-term bonds (in current simulation the number of restricted households accounts for 6.78% of the households). As argued by Turner (2011) and Blommestein and Turner (2012) as asset substitutability declines, the PDM separation from monetary policy becomes less clear. Therefore, in section 5.1 we check whether higher market segmentation induces greater need for policy coordination.

Although the assessed results are modest, the economic conditions in the US have improved to the extent, FOMC has been gradually increasing FFR since 2015. Chen *et al.* (2012) pay attention to a possible problem with working with aggregate data concerning the debt level, which may be an explanation for weak results.

Figure 3: Restricted Households' Adjustments in Long-term Bonds Holdings (%)



5 Robustness Analysis

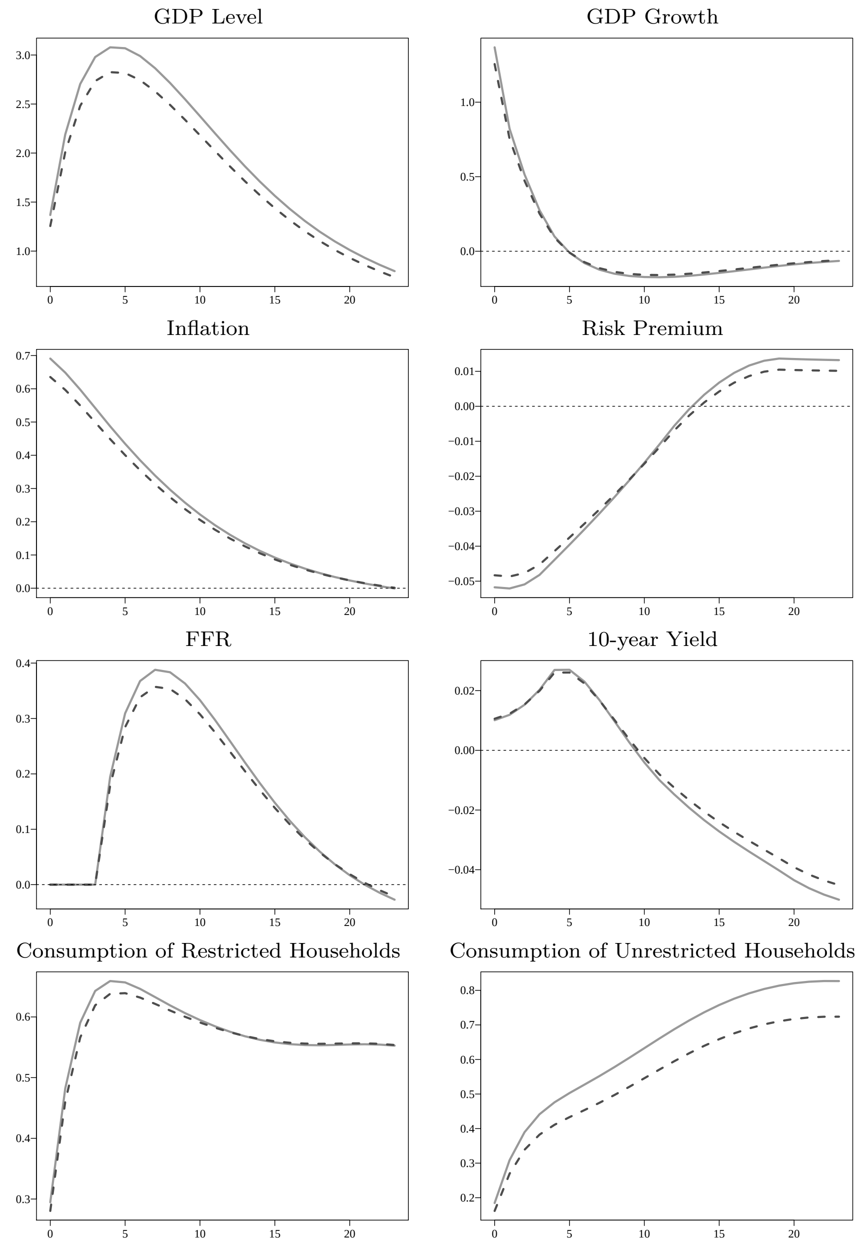
This section aims to check to what extent the baseline results from the previous section are robust to a change in parameters. Section 5.1 presents simulations with a larger scale of market segmentation, section 5.2 includes higher elasticity of risk premium and section 5.3 checks the lack of the ZLB commitment.

The task of the first two robustness checks is to check how the results change when the parameters responsible for the bond-market frictions change. These parameters could have changed due to the financial crisis which may have restructured the market. The emphasis of the third exercise is placed on monetary policy implications.

5.1 Market Segmentation

The presence of heterogeneous agents in the economy with various access to short-term bonds is a crucial assumption in the model. Here, the implications of a higher degree of market segmentation are analysed. It is assumed that the fractions of unrestricted

Figure 4: Reactions of Variables to QE (%) with Higher Market Segmentation



and restricted households in the economy are the same, i.e. $\omega_u = \omega_r = 0.5$. In the baseline simulation, the fraction of unrestricted agents is calibrated to account for 93.22% of households in the economy. This assumption indicates that the vast majority of households can modify their portfolios through both long-term and short-term securities. Furthermore, the posterior estimate is far from the prior.

The motivation for this check is that the agents may have changed their preferences for the analysed assets. This is due to the financial crisis of 2007 which could have increased the market segmentation. Therefore, the agents who traded in both types of assets before the crisis, could have switched to only one type due to the perceived rise in risk.

Figure 4 shows the reaction of the same variables as in the baseline simulation. The risk premium declines more than in the baseline case and the economy responds now much stronger. GDP reaches its peak of 3.08% after 4 quarters compared to the baseline reaction of 0.26%. Even at the end of the period of purchases it remains much above the highest level from the baseline scenario and higher than its level in the absence of QE by 0.80%. The bigger increase in output and inflation also forces the central bank to react more strongly after the end of the ZLB commitment which reinforces the influence of the expectation hypothesis on long-term yield.

Households react differently in adjusting their level of consumption. Unrestricted households increase their consumption during the whole simulation period. The consumption of restricted households increases in the initial periods, then falls and after 15 quarters from the beginning of QE remains constant. Therefore, QE has permanent effects on consumption of both types of agents in this case.

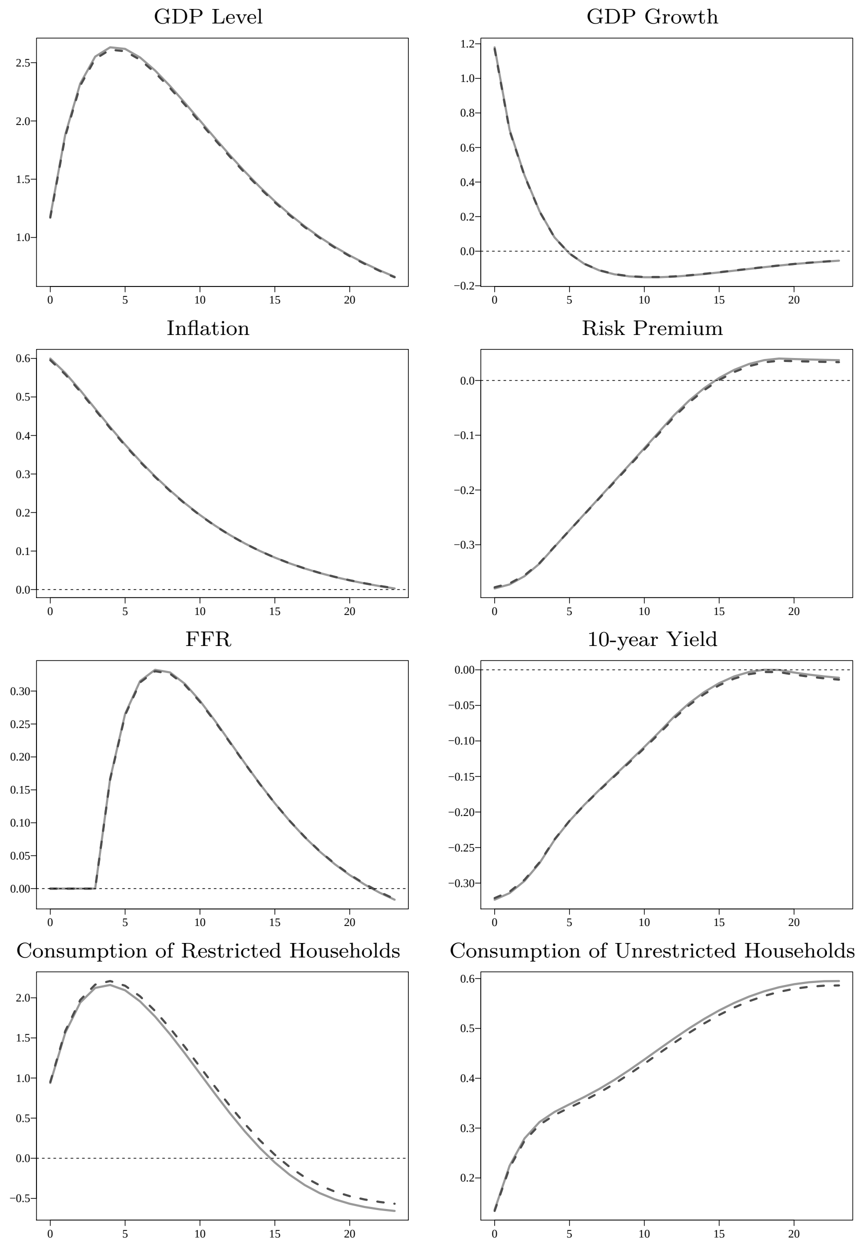
This robustness check highlights the importance of the degree of market segmentation. When all agents are the same, neither QE nor the form of financing matters for the economic reaction. This finding is consistent with results in Eggertsson and Woodford (2003) and underlines the meaning of financial frictions for the unconventional monetary policy. Contrary, the higher the market segmentation is, the bigger effects of QE are but also differences between two forms of financing increase. Hence, it requires greater coordination between monetary and fiscal authorities in the area of unconventional monetary policy and PDM to aim at the best results for the economy.

5.2 Elasticity of Risk Premium

In this section we focus on the parameter which governs the second friction in the bond market. Elasticity of risk premium ζ' is now set to 3.5/100. In the baseline experiment, this parameter is closer to zero, implying that the change in market value of long-term debt influences the risk premium and long-term yield in a limited way. Here, it is considered that the risk premium adjusts more easily to the changes in the outstanding amount.

The results presented in Figure 5 show that actually, the risk premium reacts much stronger, with the maximum fall of 38 bp compared to the baseline fall of 3 bp. This reduction in risk premium forces the long-term yield to decrease. It stimulates the real

Figure 5: Reactions of Variables to QE (%) with Higher Elasticity of Risk Premium



economy, increasing GDP and consumption. The patterns of adjusting consumption vary a lot between two types of agents.
Similarly to the baseline result, the discrepancy between the reactions of the economy to the methods of financing is negligible. It means that the decisions made by the fiscal authority do not influence the effects of the central bank's asset purchases.

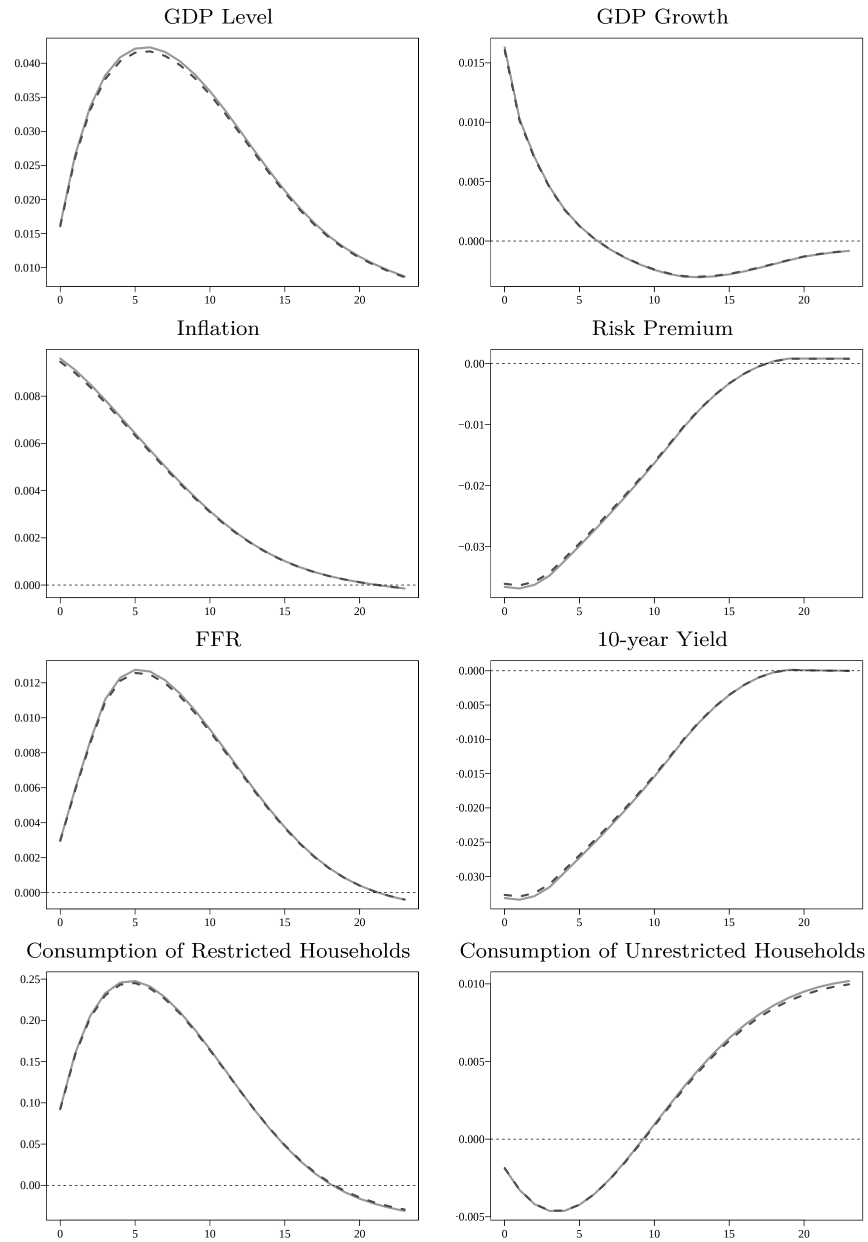
5.3 Zero Lower Bound

The central bank's decision to keep its policy interest rate at the ZLB can improve the effects of QE. In this section we assume that the central bank does not commit to keep the short-term interest rate at the ZLB for the first 4 quarters of the purchases so it acts entirely according to the Taylor rule in (3.5). This assumption aims to check whether the ZLB commitment influences Ricardian equivalence and how the reaction of the economy changes compared to the baseline case. The results are illustrated in Figure 6.
The lack of the ZLB commitment does not change the conclusions for near-Ricardian equivalence from the baseline simulation which means that the form of financing QE is still unimportant. However, the absence of such a commitment causes worse economic reactions. In particular, it has significant implications for the reaction of consumption. Restricted households react similarly to the baseline case, however in the last five quarters of QE operations, their consumption level falls below the level without QE. Contrary, the consumption of unrestricted households is lower in the first 10 quarters.
The current results underline the role of the ZLB commitment in stimulating the economy. The 4-quarter commitment from the baseline simulation induces better reactions of the economy than the lack of such a commitment (at peak, GDP growth is 8-fold higher and GDP level is more than 6-fold higher with the commitment). Hence, the relevant interest rate policy may reinforce the effects of QE.

5.4 Comparison of Results

The results illustrated in the previous parts of this paper indicate that, in the most cases, the differences between effects caused by tax-financed or by debt-financed QE are negligible. In order to see whether the reactions of variables differ substantially between the two forms of financing QE quantitatively, an analysis is conducted in this part of the paper. It includes the whole period of the QE programme, i.e. 24 quarters.
Firstly, the level of reactions of particular variables is measured in each period of the purchases. Next, these responses to QE are discounted at period 0 by the average discount factor $\bar{\beta} = \dfrac{\omega_u \Xi^u/\Xi^r \beta_u + \omega_r \beta_r}{\omega_u \Xi^u/\Xi^r + \omega_r}$. The formula for the sum of discounted

Figure 6: Reactions of Variables to QE (%) with Higher Elasticity of Risk Premium



results is given by

$$\Psi^f = \sum_{t=0}^{23} \bar{\beta}^t \hat{x}_{z,t}^f. \tag{18}$$

Here, $\hat{x}_{z,t}$ denotes the response of a log-linearised variable in period t with superscript $f \in \{bond, tax\}$, where *bond* and *tax* denote the cases of financing QE fully by short-term debt or by taxes respectively. The formula is computed for each of the four scenarios used in simulations:

(1) baseline case described in section 4.2,
(2) higher market segmentation case described in section 5.1,
(3) higher elasticity of risk premium case described in section 5.2,
(4) lack of the ZLB commitment case described in section 5.3.

Note that the average discount factor depends on fractions (ω_u and ω_r) of households, so it will be different for the second scenario than to the rest. The per cent difference between the alternative reactions is measured by ψ_i defined as

$$\psi_i = 100 \left(\frac{\Psi_i^{bond}}{\Psi_i^{tax}} - 1 \right) \%, \tag{19}$$

where subscript $i \in \{1, 2, 3, 4\}$ corresponds to one of the scenarios listed above. The results are shown in Table 2.

Table 2: Comparison of Results (%)

Variable	ψ_1	ψ_2	ψ_3	ψ_4
GDP Level	1.39	8.88	0.74	1.41
GDP Growth	1.36	8.49	0.60	1.32
Inflation	1.38	8.09	0.50	1.36
Risk Premium	1.16	−3.36	−1.59	1.31
FFR	1.36	7.52	0.30	1.38
10-year Yield	1.20	22.06	−1.21	1.33
Consumption, Restricted Agents	−0.25	1.14	−9.88	0.40
Consumption, Unrestricted Agents	1.79	15.14	1.75	3.89

The overall effects coincide with the conclusions derived from the baseline and robustness analyses. For the majority of cases, the reactions of economic variables considered in previous sections do not differ significantly. Therefore, the previous results are robust to different regime and policy changes. Consequently, near-Ricardian equivalence does hold.

The biggest differences arise in the second scenario, thus when the market segmentation is high. The existence of a segmented market makes the QE programmes be efficient. Moreover, the presence of heterogeneity allows to break Ricardian equivalence. Since the two groups of agents with different preferences for assets are more distinct in this case, the form of financing is more noticeable. The total GDP

reaction is 8.88% higher when the government issues debt to finance the programme than when it finances QE by taxes. The debt financing allows to reduce the 10-year yield by 22.06% more than the tax financing. Since the decrease in long-term yields is treated as the most important indicator of the effectiveness of large-scale asset purchases, it may be stated that the debt-financed programmes are more successful than the tax-financed ones when the degree of market segmentation is high.
On the basis of Table 2, one may analyse redistribution effects caused by QE. These are significant in the second and third scenarios. With the high market segmentation, consumption of both types of agents is higher in the bond-financing case. However, the financing method matters much more for unrestricted agents. For them, the difference accounts for 15.14% whereas the consumption of restricted agents differs only by 1.14%. When the elasticity of risk premium is high, the households adjust their consumption differently. The restricted ones consume by 9.88% more when QE is financed by taxes. Conversely, the unrestricted agents consume by 1.75% more when the purchases are financed by short-term bonds. The existence of the meaningful redistribution effects is important from the policymakers' point of view. They should take into account that the decision about the form of financing will not touch the individuals in the same manner.
The fourth scenario assumes the lack of the ZLB commitment. The results are almost in line with the baseline case. One important exception is consumption. The total difference in the form of financing for unrestricted agents is more than twice as large as in the baseline case. Despite the negligible deviation from Ricardian equivalence for restricted household, the cases with and without the ZLB commitment point the opposite change of the total difference in consumption levels between two financing methods for this type of households. All in all, this comparison shows that implementing the ZLB commitment does not significantly change the differences between economic results due to the different financing methods.

6 Conclusions

The aim of the paper is to show how the way of financing QE2 in the US influences the economy. The paper investigates whether the deviations from Ricardian equivalence introduced by bond market segmentation are quantitatively significant. It also discusses the impact of methods of financing on the redistribution between different types of agents.
The description of QE and channels through which it may operate is presented in the paper. A DSGE model with heterogeneous access to the bond market is constructed. This is the reason why the monetary policy may be effective within the presented framework.
The main finding is that two alternative forms of financing the large-scale asset purchases, either by lump-sum taxes or by issuing short-term debt, have almost the same impact on stimulating the economic activity. The difference between the results

of the two methods and Ricardian equivalence is negligible. However, the methods of financing affect the behaviour of households. Those findings are quite robust to regime and policy changes. In general, the effects of the programme estimated in the paper are moderate.

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A Appendix

The appendix shows log-linearised equations from the model described in section 3. Letters with z subscript denote normalised variables where $x_{z,t} \equiv x_t/Z_t$, except for: $r^k \equiv R_t^k/P_t$, $w_{z,t} \equiv W_t/(Z_tP_t)$, $mc_t \equiv MC_t/P_t$, $\Xi_t^j \equiv \Xi_t^{j,p} Z_t P_t \forall_j$, $B_{z,t} \equiv B_t/(P_tZ_t)$, $B_{z,t}^L \equiv B_t^L/(P_tZ_t)$, $G_{z,t} \equiv G_t/Z_t$ and $T_{z,t} \equiv T_t/(P_tZ_t)$. Variables with hats denote log deviations from steady state, except for $\hat{\zeta}_t \equiv \ln\left(\frac{1+\zeta_t}{1+\zeta}\right)$, $r_t \equiv \ln(R_t/R)$, $r_{L,t} \equiv \ln(R_{L,t}/R_L)$ and $\pi_t \equiv \ln(\Pi_t/\Pi)$. Letters without time subscript denote steady state of the variables.

$$\hat{mc}_t = \alpha \hat{r}_t^k + (1-\alpha)\hat{w}_{z,t} \tag{20}$$

$$\hat{K}_{z,t} = \hat{w}_{z,t} - \hat{r}_t^k + \hat{L}_t \tag{21}$$

$$\hat{Y}_{z,t} = \alpha \hat{K}_{z,t} + (1-\alpha)\hat{L}_t \tag{22}$$

$$\begin{aligned} \hat{X}_t^{pn,j} &= (1-\beta_j\zeta_p)(\hat{\Xi}_t^j + \hat{Y}_{z,t} + \hat{\lambda}_{f,t} + \hat{mc}_t) + \\ &+\beta_j\zeta_p\mathbb{E}_t\left(\frac{1+\lambda_f}{\lambda_f}\pi_{t+1} + \hat{X}_{t+1}^{pn,j}\right), j = u, r \end{aligned} \tag{23}$$

$$\hat{X}_t^{pd,j} = (1-\beta_j\zeta_p)(\hat{\Xi}_t^j + \hat{Y}_{z,t}) + \beta_j\zeta_p\mathbb{E}_t\left(\frac{1}{\lambda_f}\pi_{t+1} + \hat{X}_{t+1}^{pd,j}\right), j = u, r \tag{24}$$

$$\pi_t = \frac{1-\zeta_p}{\zeta_p}\left[\chi_{pu}\hat{X}_t^{pn,u} + (1-\chi_{pu})\hat{X}_t^{pn,r} - \chi_{pu}\hat{X}_t^{pd,u} - (1-\chi_{pu})\hat{X}_t^{pd,r}\right] \tag{25}$$

$$\hat{K}_{z,t} = -\hat{z}_t + \hat{u}_t + \hat{\bar{K}}_{z,t-1} \tag{26}$$

$$\hat{\bar{K}}_{z,t} = (1-\delta)e^{-\gamma}(\hat{\bar{K}}_{z,t-1} - \hat{z}_t) + [1-(1-\delta)e^{-\gamma}](\hat{\mu}_t + \hat{I}_{z,t}) \tag{27}$$

$$\hat{r}_t^k = \frac{a''(1)}{r^k}\hat{u}_t \tag{28}$$

$$\begin{aligned} \hat{q}_t &= \bar{\beta}e^{-\gamma}\mathbb{E}_t[r^k\hat{r}_{t+1}^k + (1-\delta)\hat{q}_{t+1}] - \mathbb{E}_t\hat{z}_{t+1} + \\ &+\mathbb{E}_t\left[q_u\left(\frac{1+\zeta}{1+q_u\zeta}\hat{\Xi}_{t+1}^u - \hat{\Xi}_t^u\right) + (1-q_u)\left(\frac{1}{1+q_u\zeta}\hat{\Xi}_{t+1}^r - \hat{\Xi}_t^r\right)\right] \end{aligned} \tag{29}$$

$$0 = \hat{q}_t + \hat{\mu}_t - e^{2\gamma}S''(\hat{z}_t + \hat{I}_{z,t} - \hat{I}_{z,t-1}) + \bar{\beta}e^{2\gamma}S''\mathbb{E}_t[\hat{z}_{t+1} + \hat{I}_{z,t+1} - \hat{I}_{z,t}] \tag{30}$$

$$\begin{aligned} \hat{\Xi}_t^j &= \frac{1}{1-\beta_j h}\left[\left(\hat{b}_t^j - \beta_j h\mathbb{E}_t\hat{b}_{t+1}^j\right) - \right. \\ &\left. -\frac{\sigma_j}{1-h}\left\{(1+\beta_j h^2)\hat{C}_{z,t}^j - \beta_j h\mathbb{E}_t\hat{C}_{z,t+1}^j - h\hat{C}_{z,t-1}^j\right\}\right], j = u, r \end{aligned} \tag{31}$$

$$\hat{\Xi}_t^u = r_t + \mathbb{E}_t(\hat{\Xi}_{t+1}^u - \hat{z}_{t+1} - \pi_{t+1}) \tag{32}$$

$$\hat{\zeta}_t + \hat{\Xi}^u_t = \frac{R_L}{R_L - \kappa} r_{L,t} + \mathbb{E}_t \left[\hat{\Xi}^u_{t+1} - \hat{z}_{t+1} - \pi_{t+1} - \frac{\kappa}{R_L - \kappa} r_{L,t+1} \right] \tag{33}$$

$$\hat{\Xi}^r_t = \frac{R_L}{R_L - \kappa} r_{L,t} + \mathbb{E}_t \left[\hat{\Xi}^r_{t+1} - \hat{z}_{t+1} - \pi_{t+1} - \frac{\kappa}{R_L - \kappa} r_{L,t+1} \right] \tag{34}$$

$$\begin{aligned} C^r_z \hat{C}^r_{z,t} &+ P_L B^{L,r}_z (\hat{P}_{L,t} + \hat{B}^{L,r}_{z,t}) = \\ &= R_L P_L \Pi^{-1} e^{-\gamma} B^{L,r}_z (r_{L,t} + \hat{P}_{L,t} - \pi_t - \hat{z}_t + \hat{B}^{L,r}_{z,t-1}) + \\ &+ w_z L^r (\hat{w}_{z,t} + \hat{L}_{r,t}) + Y_z \hat{Y}_{z,t} - w_z L (\hat{w}_{z,t} + \hat{L}_t) - r^k e^{-\gamma} \bar{K}_z \hat{u}_t + \\ &- I_z \hat{I}_{z,t} + \omega_u \zeta P_L B^{L,u}_z (\hat{P}_{L,t} + \hat{B}^{L,u}_{z,t}) + \omega_u P_L B^{L,u}_z \hat{\zeta}_t - T^r_z \hat{T}^r_{z,t} \end{aligned} \tag{35}$$

$$B^L_z \hat{B}^L_{z,t} = \omega_u B^{L,u}_z \hat{B}^{L,u}_{z,t} + \omega_r B^{L,r}_z \hat{B}^{L,r}_{z,t} \tag{36}$$

$$\hat{w}_{z,t} = \hat{\varphi}^j_t + \nu \hat{L}^j_t - \hat{\Xi}^j_t, j = u, r \tag{37}$$

$$L \hat{L}_t = \omega_u L^u \hat{L}^u_t + \omega_r L^r \hat{L}^r_t \tag{38}$$

$$T^r_z \hat{T}^r_{z,t} = T_z \hat{T}_{z,t} \tag{39}$$

$$\hat{P}_{L,t} = -R_L P_L r_{L,t} \tag{40}$$

$$\begin{aligned} \hat{B}_{z,t} + \frac{B^L_z / B_z}{R_L - \kappa} \hat{B}^L_{z,t} &= \beta_u^{-1} (\hat{B}_{z,t-1} + r_{t-1}) + \frac{B^L_z / B_z}{R_L - \kappa} \beta_r^{-1} \hat{B}^L_{z,t-1} + \\ &+ \frac{(1 - e^{-\gamma} \Pi^{-1} \kappa) R_L}{R_L - \kappa} \frac{B^L_z / B_z}{R_L - \kappa} r_{L,t} + \\ &+ \frac{G_z}{B_z} \hat{G}_{z,t} - \frac{Y_z}{B_z} \hat{T}_{z,t} - \left(\beta_u^{-1} + \frac{B^L_z / B_z}{R_L - \kappa} \beta_r^{-1} \right) (\hat{z}_t + \pi_t) \end{aligned} \tag{41}$$

$$-\frac{R_L}{R_L - \kappa} r_{L,t} + \hat{B}^L_{z,t} = \rho_B \left(-\frac{R_L}{R_L - \kappa} r_{L,t-1} + \hat{B}^L_{z,t-1} \right) + \epsilon_{B,t} \tag{42}$$

$$\begin{aligned} &\frac{\hat{T}_{z,t} - G_z \hat{G}_{z,t}}{T_z - G_z} = \\ = \quad &\phi_T \left[\frac{\hat{B}_{z,t-1} + \frac{1}{R_L - \kappa} (B^L_z / B_z) \hat{B}^L_{z,t-1} - \frac{R_L}{(R_L - \kappa)^2} (B^L_z / B_z) r_{L,t-1}}{1 + \frac{1}{R_L - \kappa} (B^L_z / B_z)} \right] + \epsilon_{T,t} \end{aligned} \tag{43}$$

$$r_t = \rho_m r_{t-1} + (1 - \rho_m) \left[\phi_\pi \pi_t + \phi_y \left(\hat{Y}_{z,t} - \hat{Y}_{z,t-4} + \sum_{i=0}^{3} \hat{z}_{t-i} \right) \right] + \epsilon_{m,t} \tag{44}$$

$$\hat{\zeta}_t = \zeta' (\hat{P}_{L,t} + \hat{B}^{L,u}_{z,t}) + \epsilon_{\zeta,t} \tag{45}$$

$$(D_L - 1) \mathbb{E}_t \hat{RP}_{t+1} - D_L \hat{RP}_t + \hat{\zeta}_t = 0 \tag{46}$$

$$\hat{Y}_{z,t} = \frac{\omega_u C^u_z}{Y_z} \hat{C}^u_{z,t} + \frac{\omega_r C^r_z}{Y_z} \hat{C}^r_{z,t} + \frac{I_z}{Y_z} \hat{I}_{z,t} + \frac{G_z}{Y_z} \hat{G}_{z,t} + e^{-\gamma} r^k \frac{\bar{K}_z}{Y_z} \hat{u}_t \tag{47}$$