What Assets Should the Central Bank Purchase in a Quantitative Easing Program?*

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Abstract

The real economy normally includes many interconnected sectors. Aside from government bonds, Central Banks engaged in quantitative easing programs have expanded their balance sheets by purchasing private bonds. In this context, it is natural to wonder what the optimal mix of private and public bonds in a QE program should be. This paper develops a DSGE model with a production network and perpetual bonds and empirically evaluates different QE programs in a 2-sector economy calibrated to US data. We find that the production network provides a coordination system that makes the two heterogeneous sectors co-move when bonds from a specific sector are purchased by the central bank. The heterogeneity in agency cost is the primary factor determining the effect of quantitative easing. Purchasing bonds with higher agency costs stimulate higher output but causes higher inflation in the short run and larger deleveraging, deteriorating the economy in the medium run. Additionally, heterogeneous price stickiness and external funding constraints also make different sectors respond to the quantitative easing program unevenly. For the central bank, choosing the assets purchased in QE faces a trade-off between short-run stimulation and medium-run deterioration.

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1. Introduction

Prior to 2007, most discussions are mainly relied on conventional monetary policies following the Taylor rule to smooth the economic fluctuations caused by economic shocks. However, the 2007-2009 financial crisis and subsequent recession have highlighted the importance of the external finance market and reshaped the menu of monetary policies. The Federal Reserve (Fed) started to use conventional monetary policies as well as some unconventional monetary policies including Quantitative Easing (QE).

QE involves the purchase by the central bank of public bonds and private securities with the goals to provide liquidity to specific markets and, more generally, to stimulate the economy. QE differs from regular open market operations (OMOs) by their much larger scale, and the facts that 1) it may involve the purchase of riskier private securities, and 2) takes place when the interest rate is at its zero (or effective) lower bound and further rate cuts are not feasible. For this reason, QE was widely used during the 2008 .financial crisis and the COVID pandemic. OMOs in the form of repurchase agreements are used to help keep the federal funds rate in the target range established by the Federal Open Market Committee (FOMC) and have a negligible effect on the Fed's balance sheet (Friedman and Kuttner, 2010). In contrast, the QE programs between September 2008 and October 2014 increased the Fed's balance sheet from \$900 billion to \$4.5 trillion, and asset purchases during the pandemic increased it further from \$4.3 trillion in March 2020 to \$8.9 trillion in February 2022 (see Figure 1). Assets in the latter case included Treasury and mortgage-backed securities, commercial paper, and loans to financial institutions through the Primary Dealer Credit Facility, to major corporate employers through the Primary Market Corporate Credit Facility, to small businesses and non-profit organizations, and so on.

Understanding how monetary policy influences the real economy and the effect of monetary policy are crucial questions in monetary economics. For QE, the famous unconventional monetary policy, some dynamic stochastic general equilibrium (DSGE) models have been established by some researchers to analyze large scale asset purchases made by the central bank. Previous work by Gertler and Karadi (2011, 2013) and Sims and Wu (2021) find that under the assumption that agency frictions are more severe for private than for public bonds, central bank purchases of the former are more expansionary because they free up more capital to finance investment. Kurtzman and Zeke (2020) find that central bank asset purchases can lead to resource misallocation through their heterogeneous effect on the cost of capital of large versus small firms. Specific types of central bank purchases of imperfectly secured private claims are also studied by Curdia and Woodford (2011), Williamson (2012), and Del Negro et al. (2017). Chen, Cúrdia, and Ferrero (2012) and

Vayanos and Vila (2021) study central bank purchases of long-term government bonds.

Most of the DSGE models have considered the systematic shock in an economy without production network and explored how the QE policies respond to the systematic shock. However, there are at least two disadvantages in current models. First, a real economy is a multi-sector economy with an entangled network of specialized production. The network is interconnected through firms' input-output trade within and across sectors. Thus, economic models without a production network may be too far from reality. Second, some recent articles (e.g.Bouakez, Cardia, and Ruge-Murcia, 2009; Pasten, Schoenle, and Weber, 2020; Ghassibe, 2021) have highlighted the importance of production linkage in the transmission of conventional monetary policy shocks. Therefore, models without the production network may be too far from reality and may deliver biased economic implications about QE as an unconventional monetary policy shock in an economic model. Hence, compared with existing literature, we consider additional forms of firm heterogeneity, namely in production functions, sectoral shocks, and price rigidity, and explicitly model input-output interactions whereby firms buy and sell goods to each others as materials inputs.

This paper considers the simplest production network economy with two sectors, namely a manufacturing sector and a service sector. private-owned firms in each sector can issue sector private bonds, and there are government bonds as well in the economy. In a QE program, a specific kind of bond is purchased by a central bank to stimulate the economy with two sectors. The small network only containing two sectors reduces the difficulty to investigate the transmission of monetary policies with multiple sources of heterogeneity. Feasible estimates show substantial heterogeneity between the two sectors, including production functions, structures of intermediate material, and sector labor force. Based on this model, the question we address in this paper is whether the composition of asset purchases in a QE program matters for the transmission of monetary policy.

The remainder of the paper is organized as follows. Section 2 describes the model. Section 3 discusses the calibration strategy, including production function estimates and I-O linkage estimates. Section 4 provides quantitative evidences, and compares different IRFs of sectoral shocks. Section 5 concludes the paper and discusses the policy implications.

2. The Model

The economy consists of 1) infinitely-lived households composed of workers and bankers, 2) competitive goods-producing firms in S heterogeneous sectors, 3) continua of monopolistic competitive retailers subject to nominal price rigidities that repackage each goods-producing firm's output and convert it into a distinct good, 4) competitive firms that aggregate repackaged goods into sectoral output, 5) competitive firms that aggregate sectoral output into final output that can be consumed or turned into capital, 6) firms that produce physical capital using final output, 7) financial intermediaries that transfer money between the households and the goods-producing firms, and 8) a government that combines fiscal and monetary authorities. This structure is extended from Gertler and Karadi (2011, 2013) and Sims and Wu (2021) and has the advantage of assigning different problems—production, pricing, aggregation, etc.—to different agents in the economy to facilitate exposition.[1]

2.1 Households

Households consist of two types of infinitely-lived members, namely workers and bankers. The fractions of members who are workers and bankers are constant over time. Within the household, all workers are identical and all bankers are identical. Each banker runs a financial intermediary and faces a constant exit probability, $1-\gamma$, after which she becomes a worker. Hence, the survival rate of bankers is γ. Exiting bankers transfer their wealth to the household and are replaced by an equal number of workers who become new bankers. New bankers are granted an amount of startup wealth when they enter the financial market. Since there is perfect consumption insurance across household members, we can consider the maximization problem of a representative household with preferences,

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\ln(C_t - hC_{t-1}) - \sum_{s=1}^{S} \frac{\chi_s}{1+\eta} L_{s,t}^{1+\eta} \right] , \tag{1}$$

where $\mathbb{E}_0$ is the expectation conditional on information known at time $t=0$, $\beta \in (0,1)$ is the subjective discount factor, C_t is final consumption, $h \in (0,1)$ measures the degree of habit formation, $L_{s,t}$ is total labor used by firms in sector s, and $\chi_s, \eta > 0$ are constant parameters. Habit formation helps the model account for the consumption dynamics observed in the data, but is not essential for our analysis.

Markets are segmented and the only financial asset available to households is riskless deposits held by financial intermediaries, D_t, which pays a gross rate of return $R_{D,t}$. The household budget constraint is

$$P_t C_t + D_t + P_t \Xi = R_{t-1}^D D_{t-1} + \sum_{s=1}^{S} W_{s,t} L_{s,t} - T_t + \Pi_t , \tag{2}$$

where P_t is the price of a unit of final consumption, Ξ is the real startup transfer given to the new bankers[2], $W_{s,t}$ is the nominal wage in sector $s \in \{1, 2, \ldots, S\}$, T_t is a lump-sum tax or transfer,

[1] More detailed derivatives and explanations are in the online Appendix.

[2] Following the literature, the net transfer is assumed to be constant across time. It can be understood as the

Π_t is total dividends received from all production firms as the surviving financial intermediaries do not provide dividends. In what follows, P_t serves as the model counterpart of the consumer price index (CPI) and is formally defined below.

2.2 Production

2.2.1 Goods-producing Firms

Following the traditional form of production network like Acemoglu, Akcigit, and Kerr (2016), the representative competitive firm in sector $s \in S$ produces output $\mathcal{Y}_{i,t}$ using the production function,[3]

$$\mathcal{Y}_{s,t} = A_{s,t}(A_t L_{s,t})^{\alpha_s^L}(K_{s,t})^{\alpha_s^K}(M_{s,t})^{\alpha_s^M} \quad , \tag{3}$$

where A_t is an aggregate productivity shock that affects all firms in all sectors, $A_{s,t}$ is a sectoral productivity shock that affects all firms in sector s[4], $L_{s,t}$ is labor input, $K_{s,t}$ is physical capital, $M_{s,t}$ is materials, and $\alpha_s^L, \alpha_s^K, \alpha_s^M \in (0,1)$ are elasticity parameters that satisfy the restriction $\alpha_s^L + \alpha_s^K + \alpha_s^M = 1$.

Productivity shocks follow AR(1) processes

$$\ln A_t = \rho_A \ln A_{t-1} + \epsilon_{A,t},$$
$$\ln A_{s,t} = \rho_s \ln A_{s,t-1} + \epsilon_{s,t}$$

where $\rho_A, \rho_s \in (-1,1)$ and $\epsilon_{A,t}$ and $\epsilon_{s,t}$ are innovations assumed to be independently and ientically distributed (i.i.d.) with mean zero and constant conditional variances σ_A^2 and σ_s^2 respectively

Materials of sector s's firm are an aggregate of goods produced by all firms in all sectors,

$$M_{s,t} = \prod_{j=1}^{S} (\xi_{sj})^{-\xi_{sj}} (m_{sj,t})^{\xi_{sj}} \quad , \tag{4}$$

where $m_{sj,t}$ is materials purchased from the representative firm in sector j, and ξ_{sj}^m are aggregation weights that satisfy $\sum\limits_{j=1}^{S} \eta_{sj}^m = 1$. This specification means that firms interact directly with each other as producers and consumers of the materials used as inputs of production.

The physical capital stock evolves according to

$$K_{s,t+1} = (1-\delta)K_{s,t} + X_{s,t} \ , \tag{5}$$

amount of new financial intermediaries is constant in each period. Thus, if each new financial intermediary should reach a specific level of real startup funds, then the total startup funds should be constant across time.

[3]To avoid cluttered notation and since the firm is representative, we index the firm only by the sector it belongs to.

[4]Recent researches like Foerster, Sarte, and Watson (2011) and Atalay (2017) illustrate the importance of sectoral shocks.

where $X_{s,t}$ denotes the new purchase in physical capital goods, similar to the typical setup in Carlstrom, Fuerst, and Paustian (2017), the firm faces an external funding constraint whereby it must finance a proportion of its capital evolution with external funds obtained by selling long-term bonds. As in Woodford (2001), the bonds are perpetuities with $\kappa \in [0, 1/\beta)$ being the decay parameter for coupon payments[5]. That is, a unit of bond issued in period t pays a coupon of κ^ι dollars $\iota + 1$ periods later. Denoting the total nominal coupon liability in period t that arises from all past issuances by $F_{s,t-1}$, it is easy to show that new net bond issuances are $f_{s,t} - \kappa f_{s,t-1}/\pi_t$ where $f_{s,t} \equiv F_{s,t}/P_t$ denotes the real liability (see Sims and Wu, 2021, pp. 138-139)[6]. Then, the real external funding constraint faced by the firm is

$$\psi_s p_t^X X_{s,t} \leq Q_{s,t}^F (f_{s,t} - \kappa f_{s,t-1} \pi_t^{-1}) \;, \tag{6}$$

where $\psi_s \in (0, 1)$ is the proportion denoting the fraction of physical capital expenditures that must be financed externally[7], $p_t^X K$ is the real price of physical capital goods, and $Q_{s,t}^F$ is the price of the bond issued by representative firm in s. Notice that the proportion ψ_s and the bond price may vary across sectors and , hence, are indexed by s. The "loan-in-advance" constraint in Carlstrom, Fuerst, and Paustian (2017) is the special case of (6) where $\psi = 1$ and all investment must be externally financed.

The firm maximizes

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \Lambda_{0,t} \left[\widetilde{p_{s,t}} \mathcal{Y}_{s,t} - \left(w_{s,t} L_{s,t} + p_{s,t}^M M_{s,t} + p_t^X X_{s,t} \right) + Q_{s,t}^F (f_{s,t} - \kappa f_{s,t-1}/\pi_t) - f_{s,t-1}/\pi_t \right] \;,$$

where $\Lambda_{0,t}$ is the household's stochastic discount factor, $\widetilde{p_{s,t}}$ is the real price of a unit of goods $\mathcal{Y}_{s,t}$, $w_{s,t} = W_{s,t}/P_t$ is the real wage rate in sector i, $p_{s,t}^M$ is the real price of materials aggregate. The terms in the objective function are, respectively, revenue, the value of new bond issuances, purchases of labor, materials and new physical capital goods, and coupon liabilities.

The consumption of materials purchased from the representative firm in sector j is the solution to

$$\max_{\{m_{sj,t}\}} \prod_{s=1}^{S} (\xi_{sj})^{-\xi_{sj}} (m_{sj,t})^{\xi_{sj}},$$

[5] As the duration of the bonds is $(1 - \beta\kappa)^{-1}$, common κ implies common duration. A more complicated setup can attribute different *kappa* for different kinds of bonds to mimic various durations.

[6] In the following part, real variables is defined as corresponding nominal variable divided by the aggregate price index P_t

[7] This proportion specification is attractive since it can be seen as a trade credit between the capital producer and the goods-producing firm. The importance and implication of trade credit is illustrated in recent researches, like Luo (2020), Bigio and La'o (2020), Altinoglu (2021)

subject to the constraint that $\sum_{j=1}^{S} \widetilde{p_{j,t}} m_{j,t}^{s}$ equals a given expenditure level. The solution is

$$m_{sj,t} = \xi_{sj} p_{s,t}^{M} M_{i,t} / \widetilde{p_{j,t}} \ . \tag{7}$$

2.2.2 Retailers

Retailers form a continuum in each sector s and are individually indexed by $r \in [0, 1]$. Each retailer purchases $\mathcal{Y}_{s,t}(r)$ units of net output from the representative firm in its sector. Retailers pay the same price $\widetilde{p_{s,t}}$ as goods-producing firms that employ products from sector s as intermediate input. The output available to retailers is total output net of output sold as materials input to other goods-producing firms in all sectors. That is,

$$\int_{0}^{1} \mathcal{Y}_{s,t}(r) dr = \mathcal{Y}_{s,t} - \sum_{s=1}^{S} m_{js,t}$$

The retailer indexed by r converts the undifferentiated goods $\mathcal{Y}_{s,t}(r)$ into differentiated goods $Y_{i,t}(r)$ by a linear repackaging technology $Y_{s,t}(r) = \mathcal{Y}_{s,t}(r)$. The retailer then sells its differentiated goods to a sectoral aggregator at retailer-specific nominal price $P_{s,t}(r)$. As a result of the conversion, the retailer has monopolistic competitive power and generates excess profits that will be transferred to households as dividends. The retailer takes as given the demand for its differentiated output (see (10) below), but is subject to nominal frictions that prevent it from adjusting its price in every period. We model these frictions as in Calvo (1983) with μ_s denoting the probability that the retailer will not be able to change its price in a given period. Then the standard Calvo price-setting problem for retailers emerges

$$\max_{P_{s,t}(r)} \mathbb{E}_0 \sum_{t=0}^{\infty} (\mu_s)^t \Lambda_{0,t} \left[(P_{s,t}(r)/P_t) Y_{s,t}(r) - \widetilde{p_{s,t}} \mathcal{Y}_{s,t}(r) \right]$$

where the the first term in the objective function is real revenue and the second term is expenditure on undifferentiated goods. The solution to this problem delivers a sectoral Phillips curve that depends on the sector-specific probability μ_s. Profits earned by retailers are transferred to households as dividends and form part of Π_t in (2).

2.2.3 Sectoral Aggregators

Sectoral aggregators in sector s are perfectly competitive firms that purchase output from all retailers in sector s and combine them into a sectoral good. A representative sectoral aggregator uses the CES technology

$$Y_{s,t} = \left(\int_{0}^{1} Y_{s,t}(r)^{(\zeta_s - 1)/\zeta_s} dg \right)^{\zeta_s/(\zeta_s - 1)} \tag{8}$$

where $Y_{s,t}$ is output of the sectoral aggregator and $\zeta_i > 1$ is the elasticity of substitution between goods produced in the same sector. The standard static problem of the representative sectoral aggregator is to maximize

$$P_{s,t}Y_{s,t} - \int_0^1 P_{s,t}(r)Y_{s,t}(r)dr \ , \tag{9}$$

where the first term is revenue, the second term is total expenditure on differentiated goods and $Y_{s,t}$ is given by (8). The solution to this problem delivers the demand function the will be taken as given by the retailer,

$$Y_{s,t}(r) = \left(\frac{P_{s,t}(r)}{P_{s,t}}\right)^{-\zeta_s} Y_{s,t} \ , \tag{10}$$

where $P_{s,t}$ is the sectoral price index

$$P_{s,t} = \left(\int_0^1 P_{s,t}(r)^{1-\zeta_s} dg\right)^{1/(1-\zeta_s)} . \tag{11}$$

2.2.4 Final-output Aggregators

Final-output aggregators are perfectly competitive firms that purchase output from all sectoral aggregators and combine them into final goods. This final good is available for consumption by households, for government expenditure goods by the fiscal authority, and for further transformation into physical capital by capital-good producer. A representative final-output aggregator uses the technology

$$Y_t = \prod_{s=1}^{S} (\varsigma_s)^{-\varsigma_s} (Y_{s,t})^{\varsigma_s} \ , \tag{12}$$

where ς_s are aggregation weights that satisfy $\sum_{s=1}^{S} \varsigma_s = 1$. The static problem of the final-output aggregator is to maximize

$$P_t Y_t - \sum_{s=1}^{S} P_{s,t} Y_{s,t},$$

subject to (12), where the first term is revenue and the second term is purchases of sectoral aggregates from all sectors. The solution to this problem delivers the demand function

$$Y_{s,t} = \varsigma_s P_t Y_t / P_{s,t},$$

where P_t is the aggregate price index defined as

$$P_t = \prod_{s=1}^{S} (P_{s,t})^{\varsigma_s}. \tag{13}$$

2.2.5 Capital-good Producers

Competitive capital producers take I_t units of the final good as input and produce new physical capital goods X_t using the technology

$$X_t = \left[1 - \Phi\left(\frac{I_t}{I_{t-1}}\right)\right] I_t \ , \tag{14}$$

where $\Phi(\cdot)$ is a quadratic cost function

$$\Phi\left(\frac{I_t}{I_{t-1}}\right) = \frac{\phi}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 \ , \tag{15}$$

and $\phi \geq 0$ denotes a constant parameter. The representative capital-good producer maximizes

$$\max_{I_t} \mathbb{E}_0 \sum_{t=0}^{\infty} \Lambda_{0,t} \left\{ p_t^X X_t - I_t \right\} \ ,$$

The nominal price of the input I_t is P_t, which is also the price of a unit of final consumption and government expenditure, and so its real price is 1. In contrast, the relative price of unit of capital goods is different from 1 due to the production costs $\Phi(\cdot)$. Profits earned by capital-good producers are transferred to households as dividends and form part of π_t in (2).

2.3 Financial Intermediaries

Following the typical setup, financial intermediaries transfer money between production firms and households. This kind of intermediary is a combination of investment banks, commercial banks, mutual funds, etc. A representative intermediary indexed by $\in [0, 1]$ can use its own wealth and deposits obtained from households. Not like the households, as a specialist, the financial intermediary has access to privately issued bonds holding $F_{s,t}^F(i)$, government-issued bonds holding $B_t^F(i)$, and interest-bearing reserves $RE_t(i)$ deposited in the central bank. The intermediary engages in maturity transformation in that the deposits from households are short-term liabilities, while the public and private loans (bonds) are perpetuities. Similar to Sims and Wu (2021), the balance sheet condition of intermediary i is

$$\sum_{s=1}^{S} Q_{s,t}^F F_{s,t}^F(i) + Q_{b,t} B_t^F(i) + RE_t(i) = D_t(i) + N_t(i) \ , \tag{16}$$

where $N_t(i)$ is the net wealth holding by the financial intermediary i, $Q_{b,t}$ is the price of a government bond, $D_t(i)$ is the deposits held by the intermediary i. Net wealth $N_t(i)$ evolves according to

$$\begin{aligned} N_t(i) = & \sum_{s=1}^{S} (R_{s,t}^F - R_{t-1}^D) Q_{s,t-1}^F F_{s,t-1}^F(i) + (R_t^B - R_{t-1}^D) Q_{b,t-1} B_{t-1}^F(i) \\ & + (R_{t-1}^{RE} - R_{t-1}^D) RE_{t-1}(i) + R_{t-1}^D N_{t-1}(i) \ , \end{aligned} \tag{17}$$

where $R^F_{s,t}, R^B_t$, and R^{RE}_t are the gross nominal rates of return on private bonds issued by firm in sector s, government bonds and reserves, respectively, with $R^F_{s,t} = (1+\kappa Q_{s,t})/Q_{s,t-1}$ and $R^B_t = (1+\kappa Q_{b,t})/Q_{b,t-1}$. The intermediary accumulates wealth from the premium earned in its bond holdings $R^F_{s,t}$ and R^B_t over the interest she pays to its depositors (R^D_t). This premium arises from the fact that capital markets are imperfect in the manner to be made precise below.

Recall the mechanism of exiting and entering for bankers, the objective of the representative financial intermediary operated by a banker is to maximize expected terminal net wealth (written in a value function)

$$V_t(i) = \max(1-\gamma)\mathbb{E}_t \sum_{\iota=1}^{\infty} \gamma^{\iota-1} \Lambda_{t,t+\iota} n_{t+\iota}(i) \ ,$$

where $n_t(i) \equiv \frac{N_t(i)}{P_t}$ is the real net wealth of intermediary i. As in Gertler and Karadi (2011), the intermediary could divert funds to her own household rather than to finance firm's capital projects and only a fraction of those funds could be recovered by depositors with the intermediary able to keep the uncovered fraction. As in Gertler and Karadi (2013), the intermediary's ability to keep some of the diverted funds varies across assets. Then, lenders supply funds to the intermediary subject to the incentive constraint,

$$V_t(i) \geq \theta_t \left(\sum_{s=1}^{S} \theta_s Q_{s,t} f^F_{s,t}(i) + \theta_b Q_{b,t} b^F_t(i) \right) , \tag{18}$$

where right-hand side are the assets that the banker could abscond with, $f^F_{i,t}(i) \equiv F^F_{i,t}(i)/P_t$ and $b^F_t(i) \equiv B^F_t(\ell)/P_t$ are the real production and government liability owned by the financial intermediary, θ_t is a stochastic term, $\theta_s, \theta_b \in (0,1)$ are constant parameters such that $\theta_s > \theta_b$ for all s denoting the fact that recovering private assets may be more difficult than recovering government bonds. Since θ_s may vary across sectors to show different recovering difficulty, based on the FOCs of the maximization problem, the risk premium varies across sectors as well in manner that satisfies

$$\mathbb{E}_t \left[\frac{R^F_{s,t+1} - R^D_t}{R^F_{j,t+1} - R^D_t} \right] = \frac{\theta_s}{\theta_j} \tag{19}$$

for any two sectors s and j. There is no agency concerning reserves held at the central bank. This implies that $R^{RE}_t = R^D_t$ and there is no risk premium associated with the holding of reserves in (17)

The term θ_t may be interpreted as a stochastic systematic credit risk that shows the systematic stability of the financial system. An increase in θ_t means that the intermediary would be able to keep a larger proportion of all diverted funds, but then depositors prefers to lend fewer funds to the intermediary. This will eventually increase the interest rate due to less liquidity. We assumed that θ_t follows AR(1) process

$$\ln \theta_t = \rho_\theta \ln \theta_{t-1} + \epsilon_{\theta,t},$$

where $\rho_\theta \in (-1, 1)$ and $\epsilon_{\theta,t}$ is an i.i.d. innovation with mean zero and constant conditional variance σ_θ^2

2.4 The Government

2.4.1 Fiscal Authority

The government finances its expenditure G_t by means of lump-sum taxes levied on households (T_t), transfers received from the central bank (Z_t) and the cash flow generated by the issuance of government bonds which is similar to the bonds of goods-producing firms. Then the fiscal authority is holding a balanced budget

$$P_t G_t = T_t + Z_t + Q_t^B (B_t - \kappa B_{t-1}) - B_{t-1} \ , \tag{20}$$

where B_t is the nominal existing liability of the government at period t. If we assume the real level of government liability $\bar{b} \equiv B_t/P_t$ is fixed. Then the budget constraint in real terms is

$$G_t = \tau_t + z_t + Q_t^B \bar{b}(1 - \kappa \pi_t^{-1}) - \bar{b}\pi_t^{-1} \ , \tag{21}$$

where τ_t is the real lump-sum tax, and z_t is the real net transfer from the central bank. G_t folloows the exogenous AR(1) process

$$\ln G_t = (1 - \rho_G) \ln G + \rho_G \ln G_{t-1} + \epsilon_{G,t},$$

where G is the steady state level government expenditure, $\rho_G \in (-1, 1)$ and $\epsilon_{G,t}$ is an i.i.d. innovation with mean zero and constant conditional variance σ_G^2

2.4.2 Central Bank

The central bank uses two kinds of monetary policy tools. One is changing a short term policy rate R_t. The adjustment of R_T follows a rule with zero lower bound (ZLB) and endogenous feed back similar to Taylor (1993)

$$\ln R_t = \max \left\{ \rho_R [\ln R_{t-1} + \lambda_\pi (\ln \pi_t - \ln \pi) + \lambda_y (\ln Y_t - \ln Y_{t-1})] + (1 - \rho^R) \ln R^{PR} + \epsilon_{R,t}, 0 \right\} \ , \tag{22}$$

where $\rho_R \in (0, 1)$ represents interest-rate smoothing, R is the steady state value of the policy rate, π is the inflation target, λ_π and λ_y are non negative response parameters, $\epsilon_{R,t}$ is an i.i.d disturbances with zero mean and standard deviation σ_R^2. With the absence of negative interest rate policy, following equation always holds

$$R_t^D = R_t^{RE} = R_t$$

In times of crisis, after the interest rate has been cut to its ZLB–so thatln $R_t = 0$ and no further cuts are possible–, the central bank can undertake quantitative easing (QE) whereby it purchases private and public bonds financed with interest-bearing reserves held by the financial intermediaries. Then the real balance sheet of the central bank is

$$\sum_{s=1}^{S} Q_{s,t}^F f_{s,t}^C + Q_{b,t} b_t^C = re_t \ , \tag{23}$$

where $f_{i,t}^C$ and b_t^C denote the central bank real holding amount of private bonds issued by firms in sector s and government bonds, respectively. re_t is the real reserves. Follow the setup of Sims and Wu (2021), the central bank holdings $f_{i,t}^C$ and b_t^C follows AR(1) processes:

$$f_{s,t}^C = (1-\rho_{F,s}) f_i^C + \rho^F f_{i,t-1}^C + \epsilon_{F,s,t} \tag{24}$$

$$b_t^C = (1-\rho_B) b^C + \rho_B b_{t-1}^C + \epsilon_{B,t} \tag{25}$$

where f_i^C and b^C are steady values of central bank bonds holdings, $\rho_{F,s}$, $\rho_{\in}(-1,1)$ are response parameters, and $\epsilon_{F,s,t}$ and $\epsilon_{B,t}$ are i.i.d disturbances with zero mean and constant conditional variance $\sigma_{F,s}^2$ and σ_B^2.

2.5 Resource Constraint and Market Clearing

In the equilibrium, the markets for labor, capital goods, government bonds and private bonds clear, that is

$$L_t = \sum_{s=1}^{S} L_{s,t}$$

$$X_t = \sum_{s=1}^{S} X_{s,t}$$

$$F_{s,t} = \int_0^1 F_{s,t}(i)di + F_{s,t}^C$$

$$B_t = \int_0^1 B_t(i)di + B_t^C$$

for all $s = 1, 2, \ldots, S$. Substituting out the dividends from firms (Π_t) and the lump-sum tax of transfer (T_t) from the government budget constraint (20) into (2) deliver the aggregate source constraint,

$$C_t + I_t + G_t = Y_t \tag{26}$$

Since the model does not have a closed-form solution, similar to Sims and Wu (2021), the model is solved via a first order linear approximation about the non-stochastic steady state. The approximation follows the algorithm of the standard decomposition method from Schmitt-Grohé and Uribe (2004) to solve the result. The approximation may be subject to the form of price stickiness in the model. Recent literature like Sims and Wolff (2017) and Oh (2020) highlighted that Calvo and Rotemberg model of price stickiness generate very different results in response to uncertainty shocks when employing higher-order perturbation. However, the scholars also proved the similarity of the two pricing models in the first-order approximation around a zero-inflation steady state. Thus, the result of first-order linear approximation is still robust. Besides, when considering the effects of the ZLB, this paper follows the traditional approach in previous researches and uses the toolkit suggested by Guerrieri and Iacoviello (2015). The toolkit is proved to be as accurate as global solution method, but much faster computationally.

3. Data and Calibration

The model permits any number of sectors but we consider two sectors in our benchmark calibration and experiments. For concreteness, we label the two sectors as non-services ($s = 1$) and services ($s = 2$), but this interpretation is not essential and simply allows us to calibrate some of the model parameters in an empirically meaningful manner.

3.1 Production functions

Following the strategy used by Bouakez, Cardia, and Ruge-Murcia (2009) and Ruge-Murcia (2022), the parameters of the production in two sectors are estimated from the 35 sectors input-output database (KLEMS)[8] developed by Dale W. Jorgenson and described in Jorgenson and Stiroh (2000). KLEM reports producer prices and quantities of total output, capital services, labor inputs, and material inputs for 35 U.S. sectors disaggregated at the two-digit level of the SIC for the period 1960 to 2005. For our calibration, non-services consists of 27 sectors and includes all manufacturing, agriculture, mining, and construction. Services consists of 8 sectors and includes all services and government enterprises[9].The first-order conditions that describe the optimal choice of labor and

[8]The data are available at http://scholar.harvard.edu/jorgenson/data.

[9]Referring to https://www.bls.gov/emp/tables/employment-by-major-industry-sector.htm, BLS sees government as a part of services-providing excluding special industries. This paper adopts this strategy, and takes government as a sub-sector of the service sector.

materials imply

$$\alpha_s^L = w_{s,t}L_{s,t}/\tilde{p_{s,t}}\mathcal{Y}_{s,t}$$
$$\alpha_s^M = p_{s,t}^M M_{s,t}/\tilde{p_{s,t}}\mathcal{Y}_{s,t},$$

where $p_{s,t}^M M_{s,t} = \sum_{s=1}^{S} p_{j,t}m_{sj,t}$, Using the KLEM data, we compute the wage bill, total expenditures on materials, and the value of total output for both sectors for each year in the sample, and the ratios above deliver estimates of α_s^L and α_s^M for each sector and year of the sample.Since the production function is constant returns to scale, an estimate of the capital elasticity for each sector and year is $\alpha_s^K = 1 - \alpha_s^L - \alpha_s^M$.

The final estimates of α_s^K, α_s^L and α_s^M are the sample average of these yearly estimate and their standard deviation are $\sqrt{\sigma^2/T}$ where $T = 46$ is the sample size and σ^2 is the variance of the yearly observations. Detailed estimate results including the standard error of the elasticity estimates are reported in Table 1. Note that production parameters are statistically different across the two sectors and that materials are large share of productive inputs in both sectors. The latter observation means that sectoral interactions in the market for material inputs are quantitatively important and likely to affect the transmission of QE.

3.2 Input-output(I-O) linkage

Sectoral interactions in the market for materials are summarized by an Input-Output (I-O) table. To calibrate the elements of this table in our model economy, we use data from the I-O accounts produced by the U.S. Bureau of Economic Analysis (BEA)[10]. The BEA produces a Make table that reports the production of commodities by industries, and a Use table that reports the consumption of commodities by industries[11]. All values are reported in nominal U.S. dollars. We follow Pasten, Schoenle, and Weber (2020) and Ghassibe (2021) in using both tables to estimate the elements ξ_{sj} of the I-O table[12]. The "make" table shows the production of commodities by industries. The "use" table shows how much a given product is used as intermediate material and final goods. The values reported in the tables are measured in nominal US dollar terms. Note that the first-order condition (7) implies

$$\xi_{sj} = \frac{m_{sj,t}\tilde{p_{j,t}}}{M_{s,t}p_{s,t}^M}. \tag{27}$$

[10]Data is available at https://www.bea.gov/industry/input-output-accounts-data.

[11]Since the "use" table also reports the wage and total value added of each sector, this paper also uses BEA data to calibrate the production parameters by BEA I-O data from 1997 to 2019. The result is similar to the KLEM calibration.

[12]Using both tables deals with the fact that certain commodities are coded in a sector different from the one where they are physically produced. An example is printed advertisement, which is treated as a business service even though it is produced by printing and publishing.

Thus the weight ξ_{sj} is simply the proportion of total expenditures in materials from sector s. $M_{s,t}p^M_{s,t}$ that goes to goods produced by sector j, $m_{sj,t}p_{j,t}$. The former is computed directly from the Use table by adding up the elements of its column s. The latter is obtained by first computing the proportion of good g produced by sector j as the ratio of the value of good g produced by sector j over the total value of g produced by all sectors. We then compute the numerator in (27) as the weighted sum of purchases from sector j.

We use the 15-industry I-O tables and include agriculture, mining, and construction in the non-service sector. The procedure described above delivers estimates of ξ_{sj} for each year. The final estimate of ξ_{sj} is the sample average of the results from 1997 to 2019[13] with standard deviation $\sqrt{\sigma^2/T}$ where $T = 23$ is the sample size and σ^2 is the variance of the yearly observations. Detailed results are reported in Table 2. Although the diagonal entries of the table are large, the off-diagonal entries are of the same magnitude and statistically significant, meaning that a substantial proportion of expenditures by service firms on materials goes to non-service firms and vice-versa.

3.3 other important parameters

Calibrated values for the remaining parameters are reported in Table 3. Whenever possible we follow previous the literature on QE so that our results may be comparable. A period in the model is one quarter. The subjective discount rate (β) is set to 0.995, which implies a steady-state real interest rate of 2% at the annual rate. The habit formation parameter (h) are respectively set to 0.815 following Gertler and Karadi (2013) who in turn based these figures on estimates reported by Primiceri, Schaumburg, and Tambalotti (2006). The disutility of labor in the utility function (χ_s) is set to match labor distribution between the two sectors, and thus, $\chi_1 =$ for non-services and $\chi_2 =$ for services. The Inverse Frisch elasticity of labor supply (η) is set to 4/3 based on Chetty et al. (2011), who find relatively low values of this elasticity even after considering both the extensive and intensive margins, and suggest calibrating representative agent macroeconomic models using this estimate. The survival probability of financial intermediaries is 0.95, meaning that their expected horizon is 5 years. Results are robust to using similar values. The transfer to new intermediaries is $\Xi = 0.125$, where this value is selected to be consistent with a steady-state leverage ratio (that is, the ratio of assets to aggregate net worth) of 4, as in Gertler and Karadi (2011, 2013)

As previous literature, we set the decay parameter for bond coupon payments to $\kappa = 1 - 1/40$. Following Sims and Wu (2021), we target a steady-state excess return of private bonds over the deposit rate of 300 basis points, and that of government bonds over the deposit rate of 100 basis

[13]We assume that the 2007-2009 crisis does not change the production interconnections. However, the Covid-19 pandemic distorts the production network, so we only exclude the data starting from 2020.

points at the annual rate. These figures are respectively consistent with the spreads of Baa yields and ten year Treasury yields over the Federal Funds rate. These targets imply that the fraction of financial assets that can be diverted by the intermediary is $\theta = 0.579$. We then normalize θ_s to 1 in both sectors and set $\theta_b = 1/3$. This means that the intermediary could divert the 57.9% from private assets, but only $57.9\% \cdot (1/3) = 19.3\%$ from public assets. The parameter ψ_s is set to 0.8 based on work by Zetlin-Jones and Shourideh (2017) who find that private firms use external funding to finance about 80% of their investments. The depreciation rate is set to $\delta = 0.025$, which implies an annual depreciation of about 10%. As in Sims and Wu (2021), the parameter that determines the investment adjustment cost is set to $\phi = 2$.

The aggregation weights ς_s that determine the relative size of each sector is set to match their share of GDP and, thus, $\varsigma_1 = 0.212$ for manufacturing $\varsigma_2 = 1 - 0.212 = 0.788$ for services. The elasticity of substitution in the sectoral aggregator (8) is $\zeta_s = 8$ in both sectors, which in the usual range of values used in the New Keynesian literature. The probability of no price adjustments in manufacturing and services are $\mu_1 = 0.25$ and $\mu_2 = 0.75$, respectively, which imply that prices are fixed on average for 4 months in non-service sector and 12 months in service sector. These figures are in line with micro data reported, for instance by Bils and Klenow (2004) and others. The steady-state level of government debt and expenditure as a proportion of output are 0.41 and 0.20, respectively. The former corresponds to the ratio of federal government liabilities to nominal GDP in the last quarter of 2007 before the financial crisis, and the latter is in line with NIPA data. Interest rate smoothing in the Taylor rule (ρ_R) is set to 0.8 and the inflation and output coefficients are $\lambda_\pi = 1.5$ and $\lambda_y = 0.25$, respectively. Following Sims and Wu (2021), the steady state value of central bank private bond holdings is set to zero to reflect actual Fed policy before financial crisis, while the steady state holding of government bonds as proportion of GDP is set to 6 percent.

The standard deviations and autoregressive coefficients governing the AR process are using the values suggested in Sims and Wu (2021).

4. Quantitative Analysis

4.1 Exogenous QE at steady state

Firstly, we discuss the net effect of QE when the economy is in a steady state, and analyze how the heterogeneity of the sectors influences the effect by adding heterogeneity step by step. And these steady state discussion provides a baseline result of the effect of QE policy when the economy is not at the ZLB. Before period 0, the economy is in a steady state, and the central bank makes the decision of QE, i.e., a QE policy shock hits the economy at period 0. The central bank will have three purchasing options: manufacturing sector bonds, service sector bonds, and government bonds. For each option, to fund the corresponding QE, the central bank increases the size of its balance sheet by about 4 percent relative to annualized steady state GDP at period 0. In all impulse responses figures, inflation are in annualized percentage points, and the central bank's balance sheet is expressed relative to the annualized steady state output. The other variables are expressed as percentage deviations from the steady state level. In the figures, the blue line represents purchasing manufacturing sector bonds, the red dash-dot line represents purchasing service sector bonds, and the yellow dot line represents purchasing government bonds.

4.1.1 Step 0: Symmetric Result

We start from the symmetric case, i.e., there is no heterogeneity between the two sectors. Now the two sector share common production function ($\alpha_s^M = 0.5$ and $\alpha_s^L = 0.33$), symmetric I-O linkage ($\eta_{sj} = 0.5$) and identical Calvo price rigidity parameters (μ_s=0.25). The quantitative results are shown in Figure 2.

Due to the symmetry, the two sectors are just like one integral sector. Thus, when the QE intervention hits the economy, the responses of purchasing manufacturing sector bonds and service sector bonds are identical. Since the QE increases the demand for bonds, the price of private bonds should also increase. Higher price release the funding constraint, and then the capital funded by external funding is stimulated and causes an immediate increase in capital price. The new capital is supported by an about 1.1 percentage point increase at the peak in investment. Then, output and employment increase as well. As the QE policy generates more liquidity, inflation should also increase. In this symmetric environment, an about 0.23 percentage point increase of aggregate output at the peak is related to about 0.5 percentage point inflation cost.

However, as time passes, when the balance sheet of the central bank is shrinking, the output, capital, and investment starts to fall after reaching the peak, and finally reach a level worse than the steady state. This inverse effect of QE policy should be related to the feature of capital accumulation. In the model, more capital accumulation implies more issuance of private bonds. The payment of private bonds can be financed by either the issuance of new bonds or the revenue of production. The representative firm prefers the former approach when the QE policy provides adequate liquidity. As QE policy is exiting gradually, the firm has to deleverage. More fraction of revenue is occupied by the payment of bonds for a long time since the duration of the bonds is relatively long (when $\kappa = 1-40^{-1}$, the duration is 10 years). Then during the process of deleverage, the firm should restrict new capital purchasing, and the aggregate investment should be suppressed as well. Meanwhile, the initial capital expansion stimulated by QE policy also generates huge replacement costs during the following several periods. The high level of capital also boosts the wage above its steady state. Thus, because of the deleverage, higher replacement cost, and higher labor remuneration, the capital of the firm, the employment, and the output may decrease to the negative deviation level.

Consistent with previous literature, as $\theta_s > \theta_b$, purchasing private bonds stimulates larger expansion and generates a larger inverse effect compared to purchasing public bonds. An about 0.06 percentage point increase in aggregate output at the peak is associated with about 0.17 percentage point of inflation cost.

4.1.2 Step 1: Production Network with Common Price Rigidity

In step 1, compared to the symmetric case, we add some features of heterogeneity: production technology shown in Table 1 and I-O linkage shown in Table 2. The two sectors still share common price rigidity (μ_s=0.25). The quantitative results are shown in Figure 3. The IRFs in Figure 3 are quite similar to Figure 2, i.e., the two sectors. There are only some negligible disturbances in the sector relative price. Although the two sectors bear different production technologies, the production interactions provide a co-move framework and make the two sectors expand evenly when QE policy issues. This finding is not quite surprising. Previous literature, like Bouakez, Cardia, and Ruge-Murcia (2009, 2014), has already pointed out that heterogeneity in price rigidity is a principal factor explaining the sectoral differences to a conventional monetary policy.

4.1.3 Step 2: Benchmark Result

In step 2, we produce our benchmark result: an economy with heterogeneous production technology and heterogeneous price rigidity between sectors as shown in Table 3. Now the manufacturing sector is more flexible in pricing. Figure 4 shows the IRFs of the benchmark economy. The blue line showing the effect of purchasing manufacturing sector bonds still coincides with the red dash-dot line for service sector bond purchases. Although the two sectors bear different technology and play different roles in the production network, aggregate responses of different bonds are almost identical. Both kinds of private bond purchases cause about a 0.3 percent increase in total output at the peak with an inflation cost of 0.3 percentage points. In each sector, different private QE bond purchases stimulate identical trends of further labor input change and cause similar capital input change in each sector. These similarities imply the importance of some homogeneity in the economy.

As expected, the heterogeneity in price rigidity between the two sectors not only causes uneven changing levels in sector output, sector employment, and sector wage but also makes the two sectors respond differently in sector relative price and sector capital. Right after the QE policy hits the economy, the relative price of the manufacturing sector is higher than the steady state while the relative price of the service sector is lower than the steady state. The service sector in which the private QE stimulates an immediate extra increase in capital input at period 0. By contrast, the private QE causes an additional about 0.1 percent reduction of capital in the manufacturing sector at period 0 while capital of both sectors increases steadily in the following periods. The explanation for the price gap should be straightforward. Due to the feature of sticky pricing, the service sector is less sensitive to the inflation caused by QE. A lower probability of price adjustment pushes the service sector price to decrease. The sector price disparity generates two opposite effects. On the one hand, the disparity makes the firms in the service sector less profitable and suppresses their production and capital accumulation. On the other hand, since the final-output producer uses a Cobb-Douglas production function, lower sector relative price increases the demand for the service sector and then stimulates the service sector production. Because of the I-O interaction, the magnitude of price disparity is controlled, and the latter effect dominates the former one. Thus, the service sector shows immediate capital expansion, a relatively larger increase in employment, and higher output. The higher output makes the products of the service sector relatively abundant and widens the price gap in turn. However, as the QE policy releases the funding constraints of the two sectors together, the capital of both sectors increases steadily in the following periods. The changing trends of other sector variables are also quite similar.

4.1.4 Step 3: Higher Agency Cost in Service Sector

The coincidence illustrates the co-move of the two sectors with a production network. Our next step is to investigate if the co-move will be broken by adding more heterogeneity. In the real world, assets in different sectors should possess different default risks, and different kinds of bonds may be under different regulation, etc. All of these features may result in heterogeneity in agency friction and corresponding risk premium. In our model, this kind of heterogeneity can be mimicked by setting heterogeneous parameter θ_s as equation (19) shown. Our first experiment is to set $\theta_1 = 2/3$ and $\theta_2 = 1$, i.e., the service sector faces higher agency friction. Except for the heterogeneous θ_s, the whole environment is identical to the benchmark. Corresponding quantitative results are shown in Figure 5.

The coincidence disappears although any kind of QE is still a bond purchase of about 4 percent of steady state GDP. In Figure 5, purchasing the bonds of the sector with higher agency friction generates higher changing effects in every panel, like higher aggregate output, investment, employment, and inflation costs. Furthermore, unlike the benchmark result, the two sectors do not share similar changing trends of sector capital and sector output. The service sector capital expands and the manufacturing sector capital decreases a lot when QE shock hits the economy at period 0. During the following periods, the sector capital converges to the steady state level. No matter which kind of bonds are purchased by the central bank, only the service sector experiences extra capital expansion. In the transmission of QE, the agency friction dominates other factors. The rule given by the equation (19) determines the evolution of bond price and return rate. Direct substitution delivers

$$\frac{(1+\kappa Q_{2,t+1})/Q_{2,t} - R_t^D}{(1+\kappa Q_{1,t+1})/Q_{1,t} - R_t^D} = \frac{\theta_2}{\theta_1}.$$

If $\theta_2 > \theta_1$, either $Q_{s,t+1} > Q_{j,t+1}$ or $Q_{j,t} < Q_{s,t}$ must hold. It implies that the bond price change of the service sector is always higher than the manufacturing factor. Therefore based on equation (6), the price change drives the funding constraint of the service sector to release more significantly than previous cases. The result in step 2 also suggests that the service sector with higher price rigidity also intends to have higher capital accumulation. Thus, capital accumulation of the service sector crowds out the manufacturing sector although QE of the purchasing manufacturing sector partly diminishes the crowding out. As QE gradually exits, the different price change due to the QE transmission also gradually disappears, and the capital of the service sector decreases continuously and converges to a steady state.

Combining the 4 figures in previous steps, in this 2-sector production network, the real reason for the less stimulative effect of purchasing government bonds still follows the logic of Gertler and Karadi (2011, 2013) and Sims and Wu (2021). As illustrated in the model and experiments, a bond with a lower risk premium denotes a lower agency friction and then generates a less changing effect. Government bonds are always the least risky asset with a quite low-risk premium, thus purchasing government bonds generates mild responses.

4.1.5 Step 4: Higher Agency Cost and Less Financial Constraint in Service Sector

Except for the agency friction driving the risk premium, the two sectors also share another common financial feature: homogeneous external funding constraint parameter ψ_s. A lower ψ_s implies that the sector is more restrictive to expanding its capital. In step 4, we set an experiment to check the further effect of heterogeneous external funding. In the experiment, the whole economy is identical to Step 3, but the manufacturing sector is more restrictive and has an external funding constraint parameter $\psi_1 = 0.4$ while the service sector still has $\psi_2 = 0.8$. This value means that only 40% of the capital expansion of the manufacturing sector can be funded externally. Intuitively, the tight funding constraint restricts the capital expansion of the manufacturing sector. Thus the aggregate effect of QE should be reduced and the gap between the two sectors should be larger than Step 3.

Figure 6 represents the corresponding quantitative results of step 4. The changing patterns of most panels are similar to Figure 5. The coincidence also disappears and the QE of service sector bonds generates the most significant effect. The heterogeneity in external funding parameters does not reverse the changing trends, and agency friction is still the primary factor. As expected, compared to Figure 5, any kind of QE stimulates less aggregate output and investment during the first several periods when the size of QE purchasing is still set to about 4% steady state output. Less aggregate investment demand also restricts the jump in capital price. However, due to the lower increase in output compared to the homogeneous constraint, a 4% increase in the central bank balance sheet generates a much larger inflation cost. Because of the heterogeneous financial constraint, the capital expansion of the service sector is stimulated more while the manufacturing sector is suppressed more. The larger capital gap between sectors pushes the output gap and relative price gap between sectors. However, since the materials of the service sector mainly consist of products from itself, the increase in the service sector is still 0.4% at a peak similar to the case of step 4.

From step 0 to step 4, a remarkable effect of the QE is always causing higher employment in both sectors during the first several periods. There are two paths. On the one hand, QE may the sector capital accumulation and then increase the demand for labor input. On the other hand, due to the I-O interactions, the production of one sector needs materials from the other sector. If the QE increases the capital unevenly, the firms with the disadvantage of capital accumulation intend to increase their labor input to narrow the output gap between the two sectors.

4.1.6 Comparison with Conventional Monetary Policy

When the economy is not at ZLB, there is room for conventional monetary policy. An interesting discussion is whether a central bank should use QE when the economy is not at ZLB. To address this question, we attempt to compare the effect of a conventional monetary policy shock on the three kinds of QE in an economy illustrated in step 4. The size of the conventional shock is controlled to generate a similar output increase at a peak as the service sector QE.

Figure 7 shows the quantitative results of the comparison. The purple dash-dot line represents the conventional monetary policy shock showing several aspects of advantages. Compared to the three kinds of QE, the expansionary shock does not have the deleverage effect which makes the economy worse than the steady state. Thus, the conventional shock boosts more aggregate output, aggregate investment, sector output, and employment after period 5. The conventional policy also generates smoother response curves. For most variables, The range of the change caused by conventional policy is less than purchasing service sector bonds. Another important advantage of the conventional policy is the lower sector disparity in sector output, capital, and relative price. This reflects less misallocation due to the exogenous policy shock. Therefore, the conventional monetary policy ought to be a better option for the central bank.

4.2 Exogenous QE at ZLB

Now we move to the classical environment for exogenous QE, the economy at ZLB which the conventional policy is unavailable. As Sims and Wu (2021)'s strategy, a systematic credit shock θ_t of 1.5 standard deviation hits the economy and generates for several periods and generates a ZLB environment for QE policies. When the shock stops, then, we label the period when the central bank may make the decision of QE as period 0. We aim to find how much a QE policy tool can change the aggregate responses in the model economy. To quantify the net effect of QE, two types of simulations are considered. In the first type of simulation, no further policy intervention, and the economy would converge to a steady state naturally. In the second type of simulation, at period 0, a QE policy shock also hits the economy. The central bank will have three options: manufacturing bonds, service sector bonds, and government bonds. The plotted impulse response lines are the differences between the corresponding two types of simulations to represent the "change" caused by the purchase of the specific bonds.

Figure 8-12 show the quantitative results of different cases. There are one-to-one correspondences between the cases shown in Figure 8-12 and the cases shown in Figure 2-5. Compared to the corresponding non-ZLB case, the magnitude of the QE net effect increases although the size of QE is fixed. This is consistent with the ZLB state which is far from the steady state. According to the diminishing marginal utility and diminishing marginal product, a fixed amount of bond purchasing naturally generates more changes at ZLB.

The changing pattern of most variables in Figure 8-12 is also quite similar to the corresponding panels of Figure 2-5. Thus, most analysis in section 4.1 is also applicable to Figure 8-12. The deleverage framework explains why some QE curves reach the negative level. In the ZLB Figures, reaching a negative level implies that using QE is worse than doing nothing at that time point. The impact of price rigidity discusses the sector discrepancy due to the QE. The heterogeneity in agency friction is still the dominant factor and heterogeneous financial constraint also contributes to the gap between sectors.

Here, the extra increase in inflation caused by QE at ZLB deserves some discussion. Traditional views normally see the surging inflation as the cost of QE at ZLB. However, an economy at ZLB for several periods implies that the economy needs more liquidity and conventional policy is not feasible to provide the necessary liquidity. Thus, this economy is exposed to deflation pressure, and the economy should benefit from the extra inflation. It is not related to a so-called “cost”, but represents a positive effect in the early periods after the introduction of QE. For example, in our model, the systematic credit shock forces the economy into a deflationary state. The inflation effect generated by QE makes the inflation level closer to the steady state.

5. Conclusion

This paper develops a S-sector DSGE model with a production network and sector heterogeneity, and empirically evaluates three different kinds of QE policies in a 2-sector economy: purchasing manufacturing sector bonds, service sector bonds, and government bonds. By adding the various kinds of heterogeneity and the production network gradually, this paper finds that input-output interactions provide a co-move mechanism. If the two sectors only have different input elasticity and input-output interactions, the two sectors change evenly for one type of QE.

Quantitative results suggest that the level of agency cost is the primary factor determining the effect of QE. When the size of QE is controlled, the effect of the manufacturing QE is identical to the service sector QE as long as the two sectors share a common friction level. Purchasing bonds with higher agency costs causes higher changes in bond prices. The price changes imply a more significant release in external funding. Therefore, purchasing bonds with higher agency costs generates larger changing effects in aggregate output and investment.

Apart from the agency cost, heterogeneity in price stickiness and the external funding constraint also influence the sector effect of QE. For a specific kind of QE, the sector with more flexible pricing is likely to have lower sector output and sector capital. A lower fraction of external funding directly reduces the upper bound of purchasing new capital.

Based on the model and analysis, what is the answer to our question: what assets should the central bank purchase in a Quantitative Easing program? The central bank confronts a trade-off problem if the above heterogeneity emerges. Although QE always immediately boosts aggregate investment, output, and employment, QE generates negative effects in later periods. The heterogeneity in agency cost implies that higher short-run stimulating must be associated with noticeable medium-run deterioration because of the deleveraging process. If the economy has heterogeneous price stickiness and funding constraints, different QE policies widen the sector gap differently. Thus, there is no exact recommendation suitable for any case. The first best choice of the central bank depends on its target and goal.

Table 1: Production function parameters

Sector	α^L Estimates	s.e.	α^M Estimates	s.e.	α^K Estimates	s.e.
Manufacturing	0.278*	0.0121	0.597*	0.011	0.125*	0.013
Service	0.395*	0.011	0.387*	0.014	0.218*	0.007

Notes: the table reports estimates of the production function parameters for each sector according to KLEM. s.e. is standard error and * denotes significance at 5 percent level.

Table 2: I-O linkage parameters

	consumer			
	Non-service		Service	
Producer	Estimates	s.e.	Estimates	s.e.
Manufacturing	0.678*	0.021	0.195*	0.015
Service	0.322*	0.021	0.805*	0.015

Notes: the table reports estimates of the I/O linkage for each sector according to BEA I/O tables. s.e. is standard error and * denotes significance at 5 percent level.

Table 3: Important Parameters for Calibration

Parameters	Value or Target	Description
β	0.995	Subjective discount rate
h	0.815	Habit formation parameter
η	4/3	Inverse Frisch elasticity of labor supply
χ_1, χ_2	$\frac{L_2}{L_1} = 4.69$	Labor disutility
γ	0.95	Survival rate of financial intermediary
Ξ	Leverage ratio is 4	Transfer to new intermediaries
κ	$1 - 40^{-1}$	Decay parameter for bond coupon payment
θ	0.579	Fraction of total financial assets that can be diverted by intermediary
θ_s	1	Recoverability parameter for private bonds
θ_b	1/3	Recoverability parameter for private bonds
ψ_s	0.80	Fraction of investment externally financed
δ	0.025	depreciation rate
ς_1	0.212	Output share of non-service
ς_2	0.788	Output share of service
ζ_s	8	Elasticity of substitution
μ_1	0.25	Probability of no price adjustment in manufacturing
μ_2	0.75	Probability of no price adjustment in service
b	0.41	Steady-state debt as proportion of GDP
G	0.20	Steady-state government expenditure as proportion of GDP
f_s^C	0	Central bank steady state holdings of private bonds
b^C	0.06	Central bank steady state holdings of private bonds
ρ_R	0.8	Interest-rate smoothing
λ_π	1.5	Inflation coefficient in Taylor rule
λ_y	0.25	Output coefficient in Taylor rule
σ_R	0.0025	Standard deviation of i.i.d disturbance in Taylor rules
ρ_θ	0.98	AR coefficient of systematic credit shock
σ_θ	0.04	Standard deviation of i.i.d. disturbance in Taylor rule
ρ_A	0.95	AR coefficient of aggregate productivity shock
σ_A	0.0065	Standard deviation of i.i.d. disturbance for aggregate productivity AR
ρ_s	0.95	AR coefficient of sectoral productivity shock
σ_s	0.0065	Standard deviation of i.i.d. disturbance for sectoral productivity AR
$\rho_{F,s}$	0.80	Smoothing of sector s bond purchases
$\sigma_{F,s}$	0.0025	Standard deviation of i.i.d. disturbance for sector s bonds purchases
ρ_B	0.80	Smoothing of government bond purchases
σ_B	0.0025	Standard deviation of i.i.d. disturbance for government bond purchases
ρ_G	0.95	AR coefficient of government expenditure
σ_G	0.01	Standard deviation of i.i.d. disturbance for government expenditure

Notes: This table lists the value of calibrated parameters or the target used to calibrate the model

Figure 1: Quantitative Easing and Federal Reserves Balance Sheet

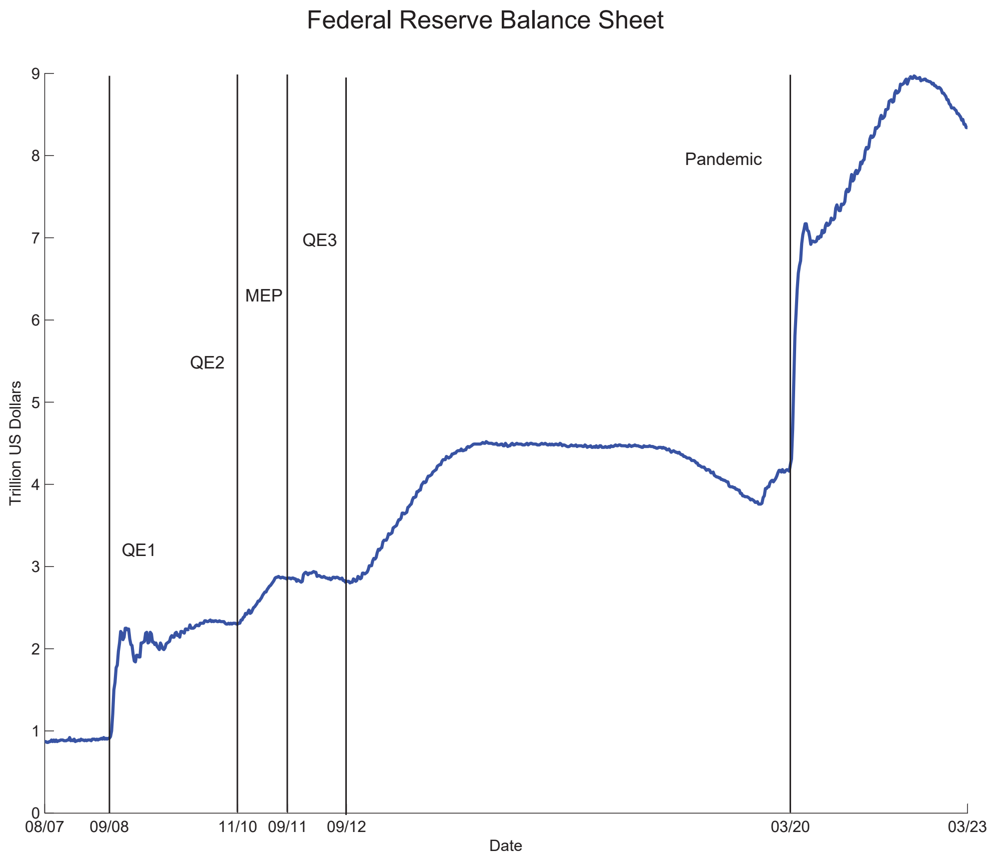
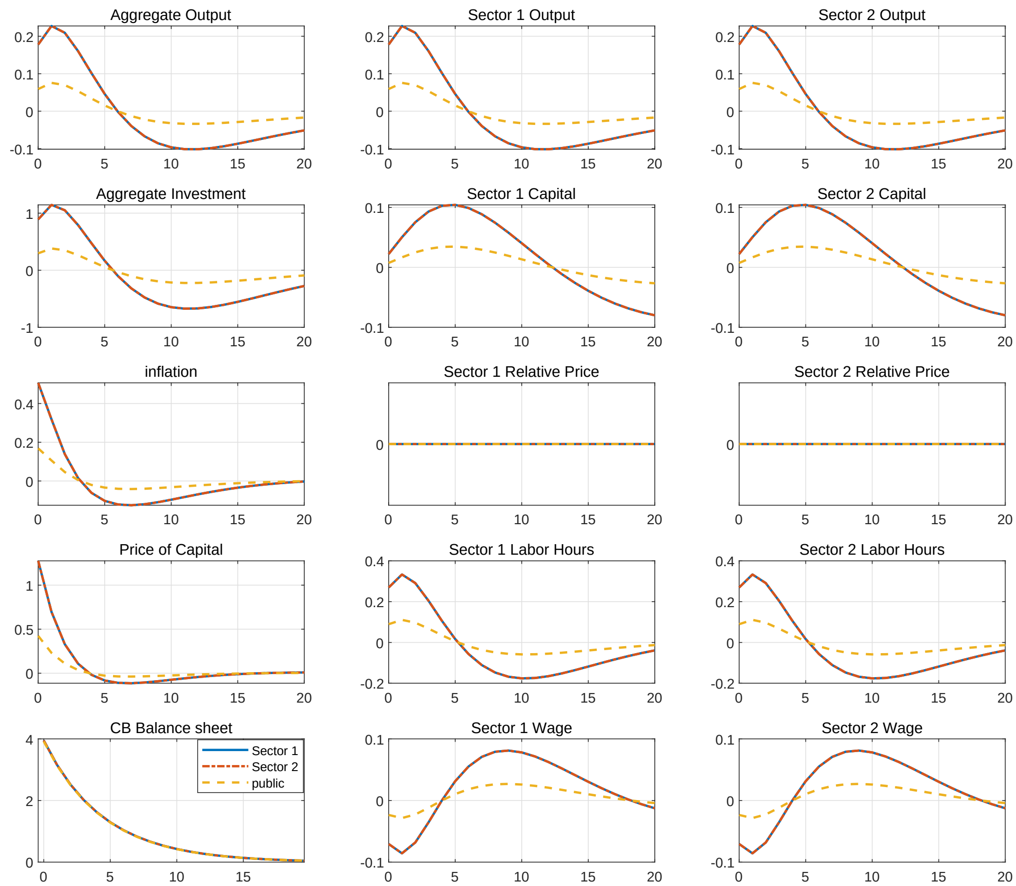
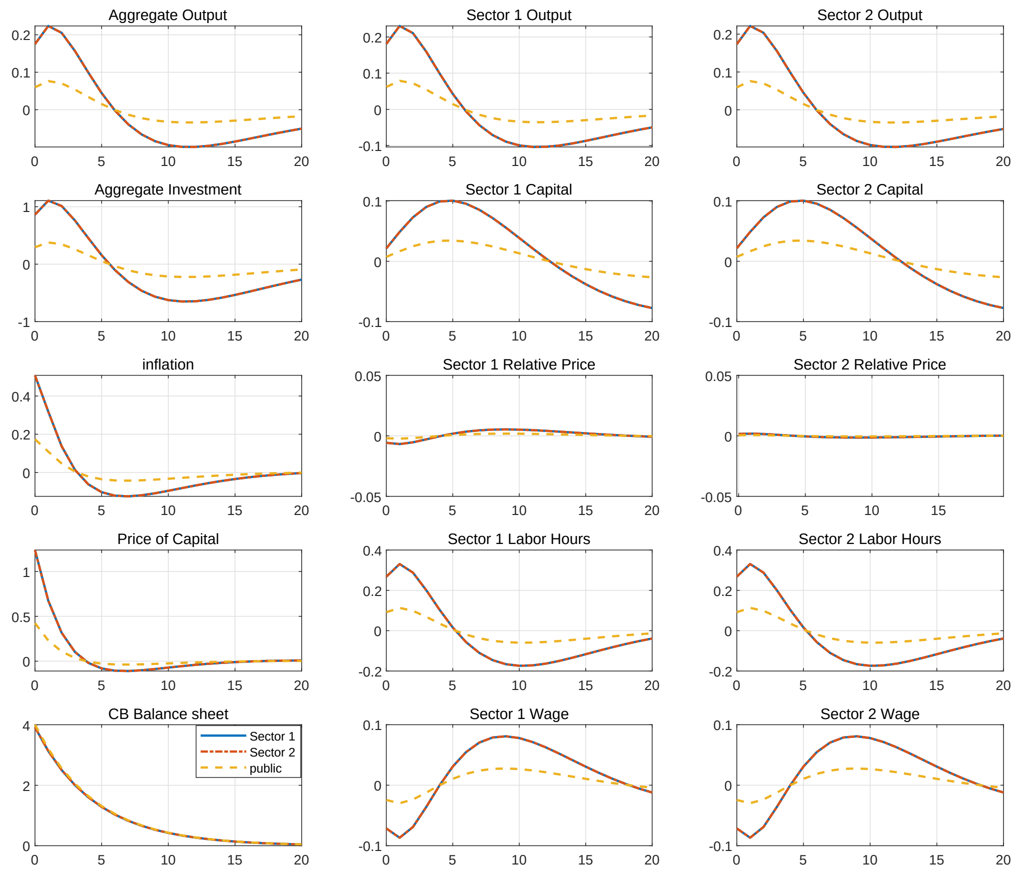


Figure 2: Symmetric Calibration



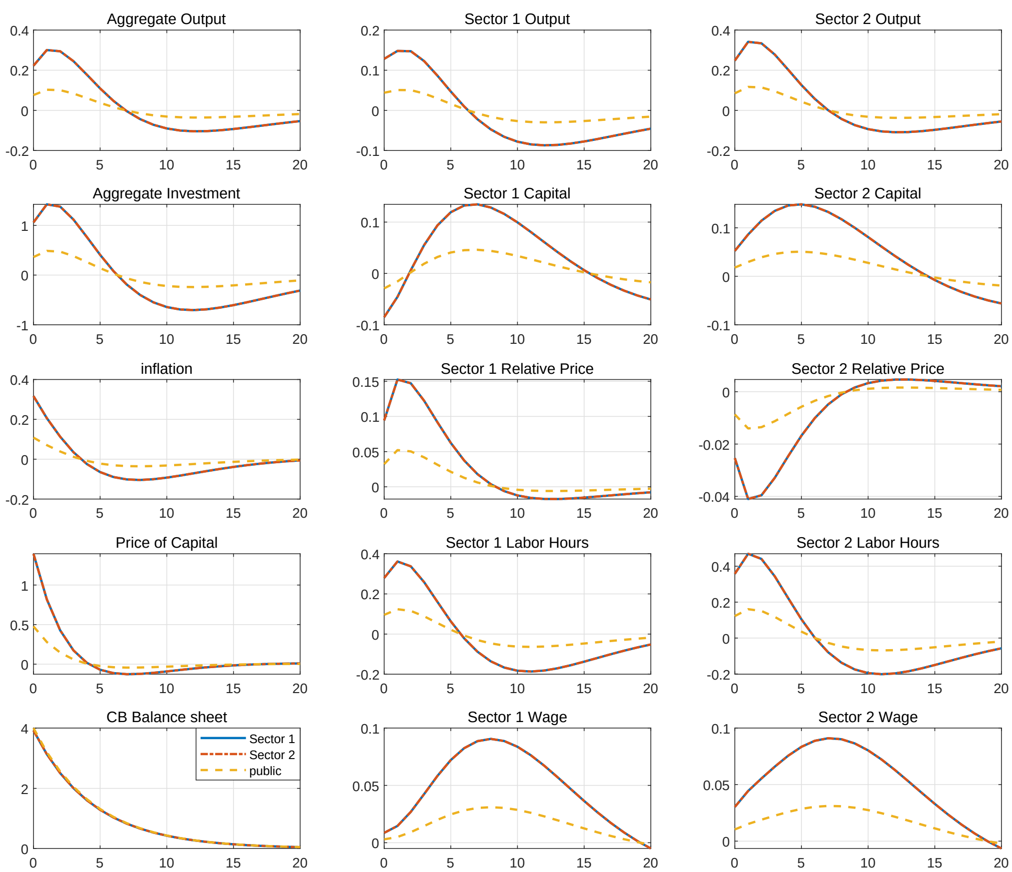
Notes: At period 0, a QE shock, where the central bank increases its balance sheet by about 4 percent of steady state GDP hits the economy. the blue line denotes manufacturing QE, the red dash-dot line denotes service sector QE, and the yellow dot line denotes public bonds QE.

Figure 3: Production Network with Common Price Rigidity



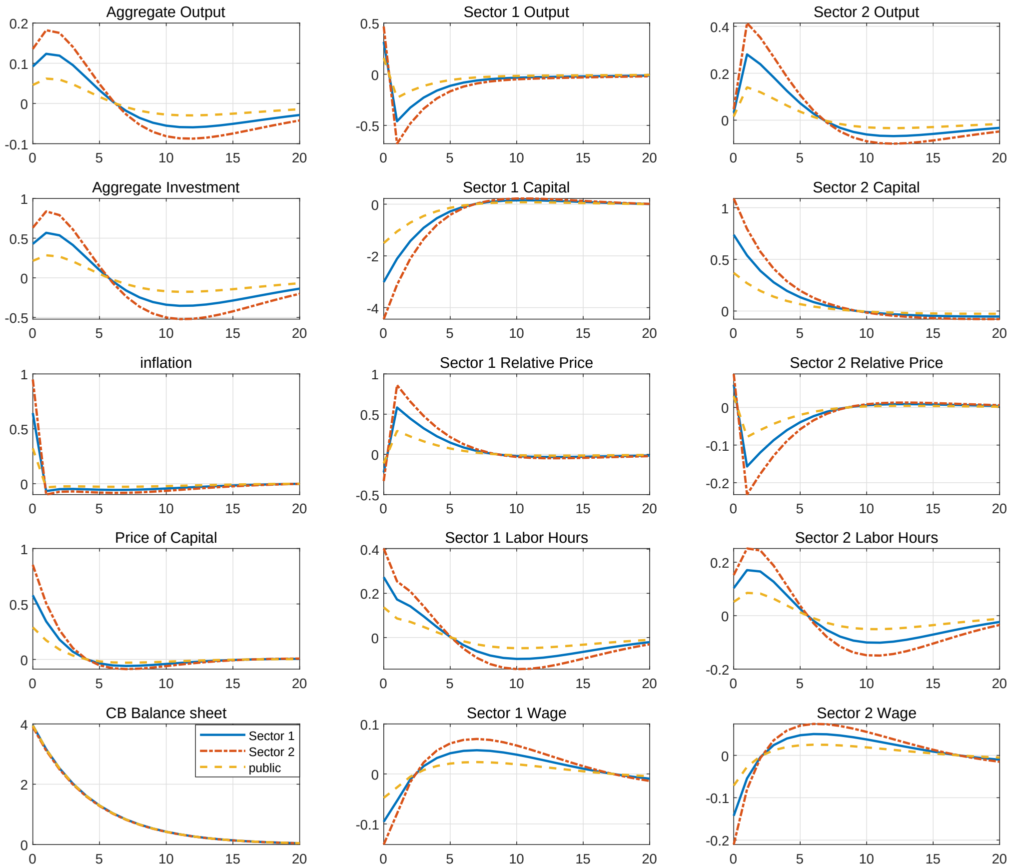
Notes: At period 0, a QE shock, where the central bank increases its balance sheet by about 4 percent of steady state GDP hits the economy. the blue line denotes manufacturing QE, the red dash-dot line denotes service sector QE, and the yellow dot line denotes public bonds QE.

Figure 4: Benchmark Calibration



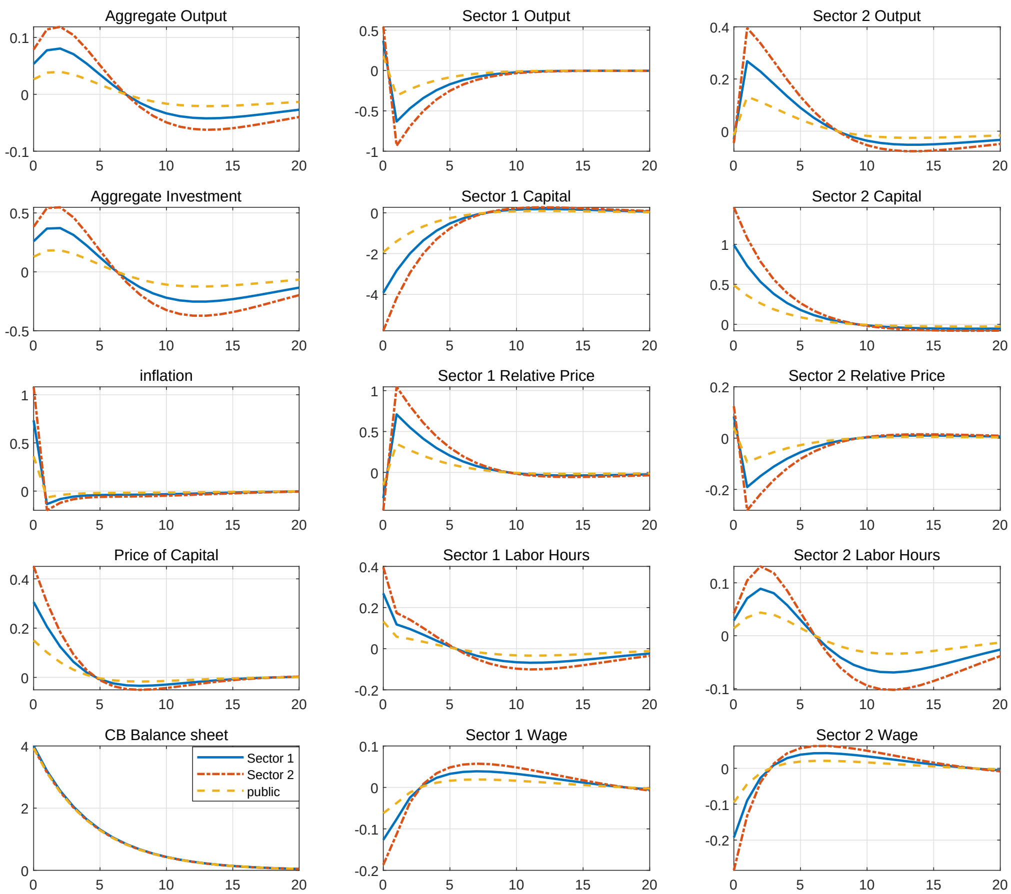
Notes: At period 0, a QE shock, where the central bank increases its balance sheet by about 4 percent of steady state GDP hits the economy. the blue line denotes manufacturing QE, the red dash-dot line denotes service sector QE, and the yellow dot line denotes public bonds QE.

Figure 5: Higher Agency Costs in Sector 2



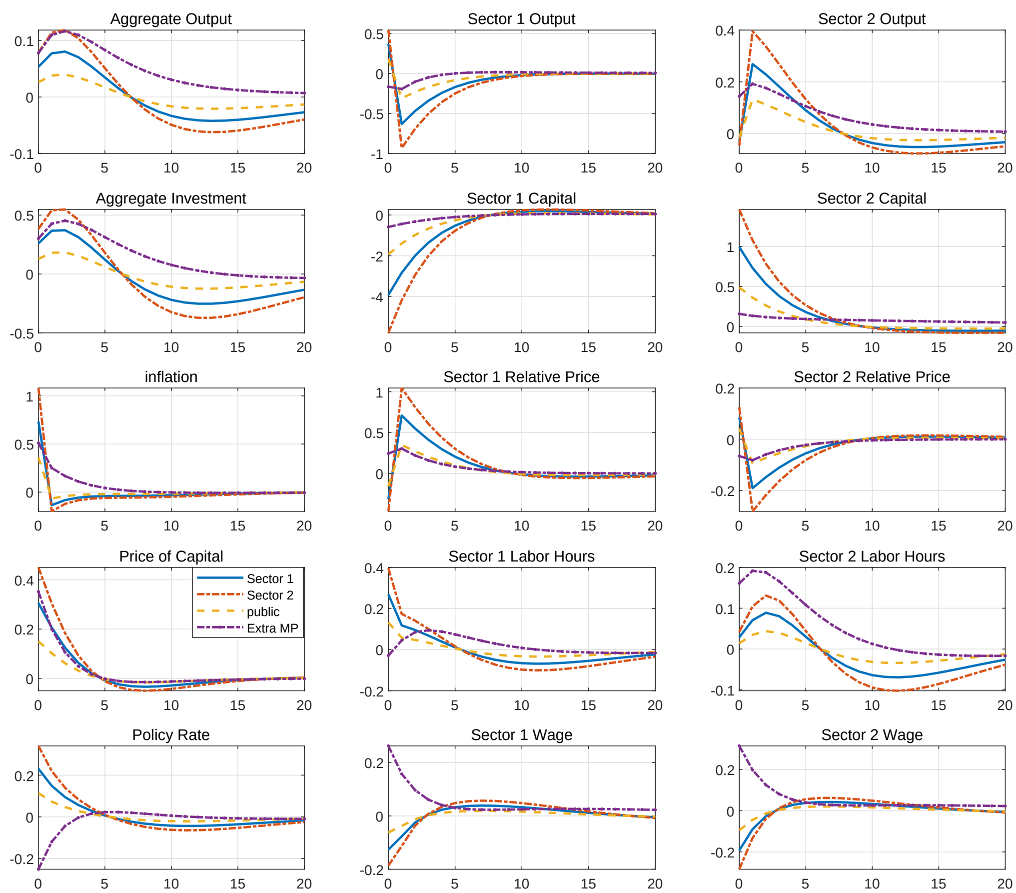
Notes: At period 0, a QE shock, where the central bank increases its balance sheet by about 4 percent of steady state GDP hits the economy. the blue line denotes manufacturing QE, the red dash-dot line denotes service sector QE, and the yellow dot line denotes public bonds QE.

Figure 6: Higher Agency Costs and Less Financial Constraint in Sector 2



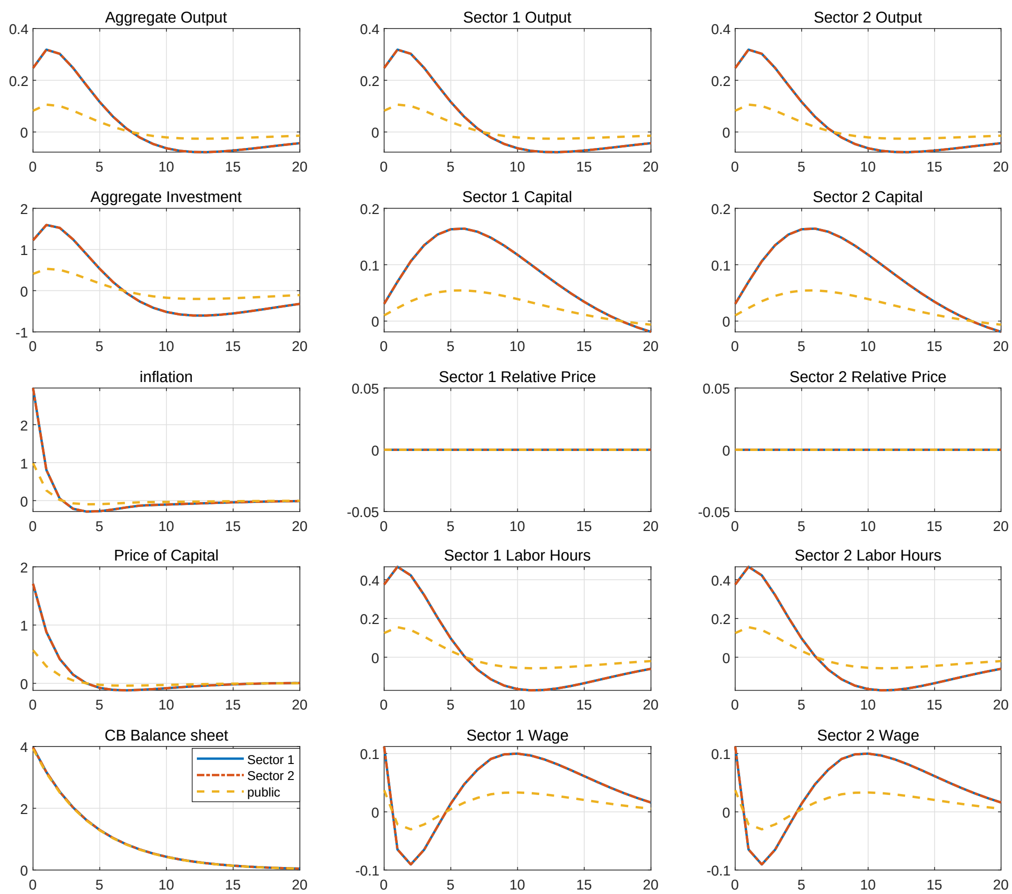
Notes: At period 0, a QE shock, where the central bank increases its balance sheet by about 4 percent of steady state GDP hits the economy. the blue line denotes manufacturing QE, the red dash-dot line denotes service sector QE, and the yellow dot line denotes public bonds QE.

Figure 7: Comparison with Conventional Policy



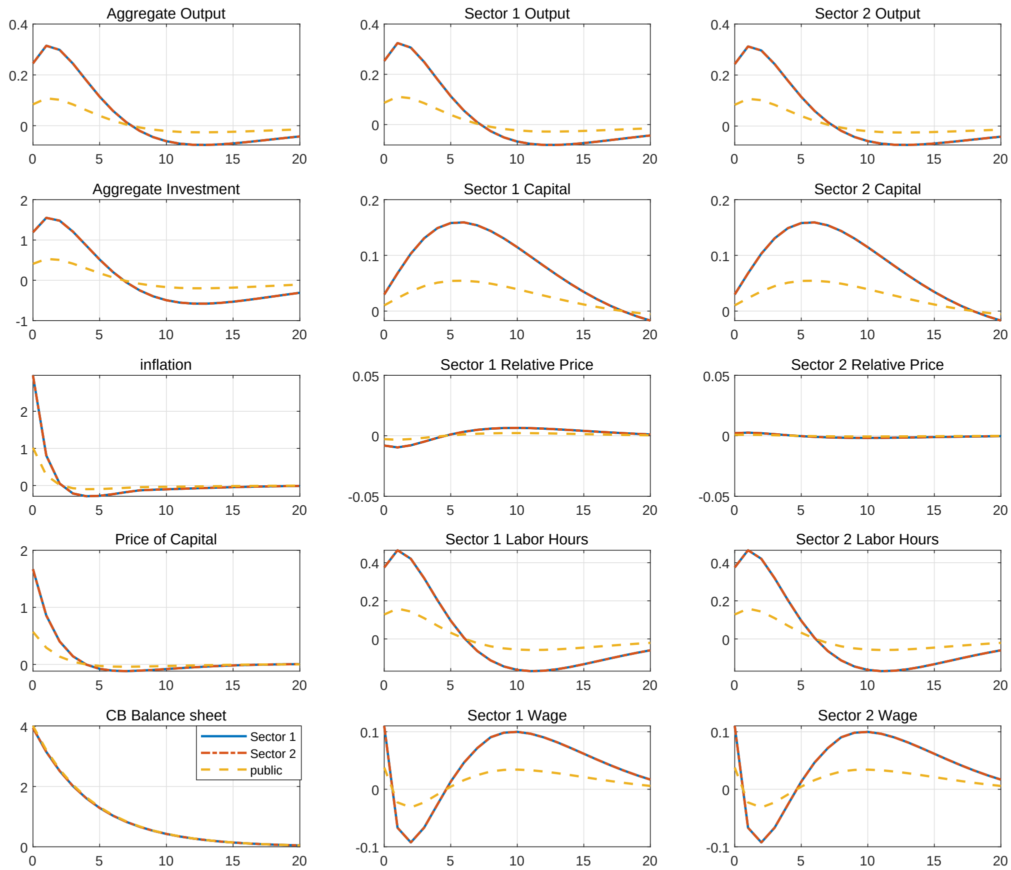
Notes: At period 0, a QE shock, where the central bank increases its balance sheet by about 4 percent of steady state GDP hits the economy. the blue line denotes manufacturing QE, the red dash-dot line denotes service sector QE, the yellow dot line denotes public bonds QE. and the purple dash-dot line denotes conventional monetary policy.

Figure 8: Symmetric Calibration (ZLB)



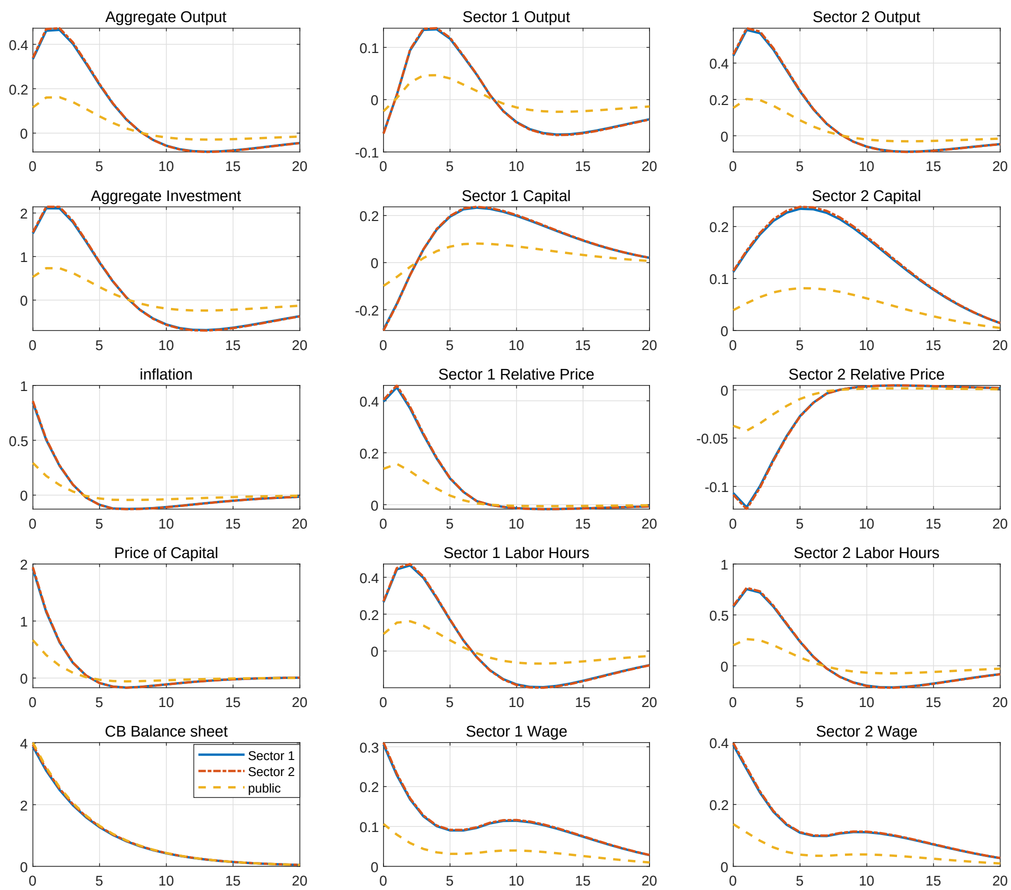
Notes: At period 0, a QE shock, where the central bank increases its balance sheet by about 4 percent of steady state GDP hits the economy. the blue line denotes manufacturing QE, the red dash-dot line denotes service sector QE, and the yellow dot line denotes public bonds QE.

Figure 9: Production Network with Common Price Rigidity (ZLB)



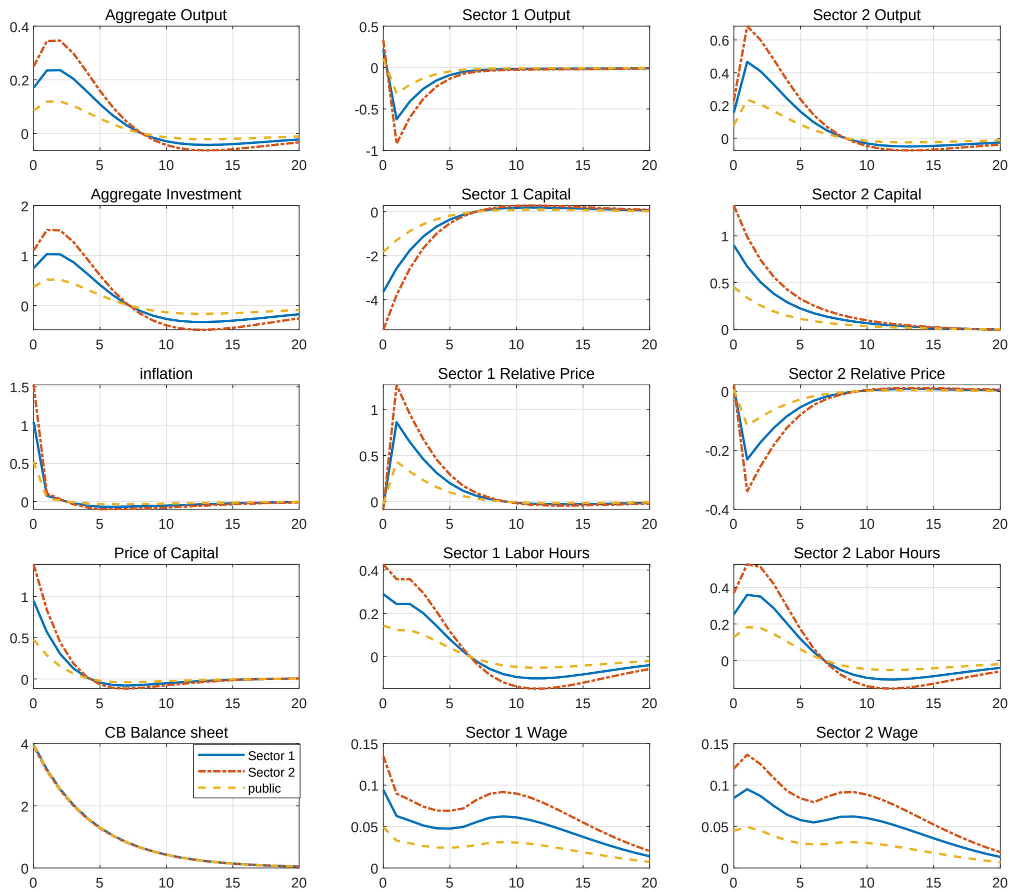
Notes: At period 0, a QE shock, where the central bank increases its balance sheet by about 4 percent of steady state GDP hits the economy. the blue line denotes manufacturing QE, the red dash-dot line denotes service sector QE, and the yellow dot line denotes public bonds QE.

Figure 10: Benchmark Calibration (ZLB)



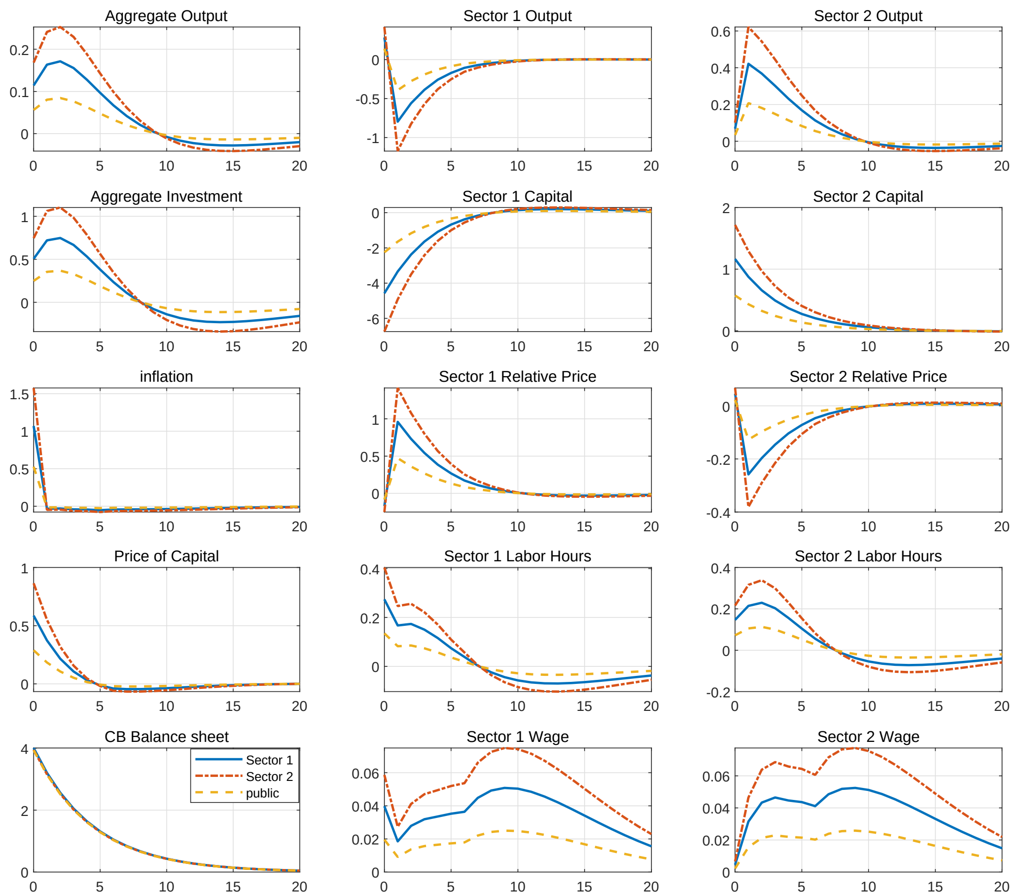
Notes: At period 0, a QE shock, where the central bank increases its balance sheet by about 4 percent of steady state GDP hits the economy. the blue line denotes manufacturing QE, the red dash-dot line denotes service sector QE, and the yellow dot line denotes public bonds QE.

Figure 11: Higher Agency Costs in Sector 2 (ZLB)



Notes: At period 0, a QE shock, where the central bank increases its balance sheet by about 4 percent of steady state GDP hits the economy. the blue line denotes manufacturing QE, the red dash-dot line denotes service sector QE, and the yellow dot line denotes public bonds QE.

Figure 12: Higher Agency Costs and Less Financial Constraint in Sector 2 (ZLB)



Notes: At period 0, a QE shock, where the central bank increases its balance sheet by about 4 percent of steady state GDP hits the economy. the blue line denotes manufacturing QE, the red dash-dot line denotes service sector QE, and the yellow dot line denotes public bonds QE.

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