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

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**Abstract**

This paper studies large-scale asset purchases in an economy with heterogenous production sectors and asks whether different asset purchases have different aggregate and sectoral effects. Sectors are heterogeneous in price rigidity, production function, and agency costs, and interact with each other in the market for intermediate goods. Results show that depending on the asset, purchases induce different sectoral responses from the interaction between price rigidity and agency costs.

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# 1. Introduction

Quantitative easing (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.

A central bank pursuing QE can potentially choose among several public and private assets, and so, the question we address in this paper is whether the composition of asset purchases matters for the transmission of unconventional monetary policy. In particular, we consider an economy where financial assets include, in addition to bonds issued by the government, bonds issued by firms in heterogeneous sectors. Sectors are heterogeneous in price rigidity, production functions, agency costs, and financial constraints, and buy goods from each other as materials inputs. In order to keep the scope of this project tractable, we consider two sectors, which are very loosely interpreted as manufacturing and services, and three QE policies, namely, purchases of government bonds and purchases of bonds issued by firms in each of the two sectors. To shed light on the role of the different sources of heterogeneity, we carry out policy experiments under a benchmark and alternative calibrations.

Our model builds on previous work by Gertler and Karadi (2011, 2013) and Sims and Wu (2021) who 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. While this is also the case in our model initially, we also find that after about seven quarters, private-asset purchases can become contractionary due to the deleveraging by firms, which eventually face increased coupon payments on their debt. The result that private bonds are more expansionary than public bonds in the short-run, but potentially contractionary in the medium run, means that the former may not dominate the latter as the best object of central bank purchases in a QE program. 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. Compared with their work, we consider additional sources of heterogeneity and show that heterogeneity in price rigidity interacts with heterogeneity in agency costs and financial frictions in a nontrivial manner. We also find that at this coarse level of disaggregation, the quantitative effect of heterogeneity in production functions and input-output is limited and we provide an explanation for this result.

Specific types of central bank purchases of imperfectly secured private claims are also studied by Curdia and Woodford (2011), Chen, Curdia, and Ferrero (2012), Williamson (2012), and Del Negro, Eggertsson, Ferrero, and Kiyotaki (2017). Curdia and Woodford study central bank lending to heterogenous households in an environment with credit frictions and show that there is a role for targeted asset purchases when financial markets are impaired. Chen, Curdia, and Ferrero estimate the effects of central bank bond purchases in an economy with segmented markets and limits to arbitrage (see also Vayanos and Vila, 2021). Williamson considers private asset purchases by the central bank in a search model and concludes that they only have an effect when the bank offers better terms to borrowers than they would obtain from private lenders. Del Negro, Eggertsson, Ferrero, and Kiyotaki examine the effects of liquidity provision by the government during a financial crisis and find that it can greatly limit the loss of output and employment.

In recent work, Karadi and Nakov (2021) study the optimality of central bank purchases after a shock to the banks' equity capital, and argue that in an environment where the constraint on the banks' balance sheet binds only occasionally, asset purchases may not always be effective. Empirical literature includes Foley-Fisher, Ramcharan, and Yu (2016), who find that the Maturity Extension Program (MEP) launched by the Federal Reserve in 2011 relaxed financial constraints for some firms by affecting the bond market risk premia, and Koetter (2020), who finds that the Securities Markets Program of the European Central Bank (ECB) increased lending by private banks in Germany with heterogeneity across lending components (commercial, retail, etc.).

The main results of the analysis are the following. First, price rigidity is a key source of heterogeneity in the effects of the QE policy with the sector with most rigid prices benefiting the most for the expansionary policy. Second, input-output interactions lead to the comovement of output and investment across sectors despite the effects of differential price rigidity across sector and dampens the heterogeneity in sectoral responses. Third, as reported in previous literature, the expansionary effects of the QE policy are largest when the central bank purchases the bond most subject to agency costs. However, we document a deleveraging effect that induces a contractionary effect, which is also the largest for the bond most subject to agency costs. As a result, the central bank faces an intertemporal trade-off when deciding what bonds to purchase in a quantitative easing program.

The paper is organized as follows. Section 2 presents the model. Section 3 discusses our calibration strategy. Section 4 examines the quantitative implications of the model. Section 5 concludes and discusses policy implications.

# 2. The Model

The economy consists of 1) households composed of workers and bankers, 2) competitive goods-producing firms in $S$ heterogeneous sectors, 3) continua of monopolistic competitive retailers that repackage the goods-producing firm's output and convert it into differentiated goods, 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 use final output to produce physical capital, 7) financial intermediaries that transfer resources between households and goods-producing firms, and 8) a government that combines fiscal and monetary authorities. This structure is similar to that in Gertler and Karadi (2013) and has the advantage of assigning different problems—production, pricing, aggregation, etc.—to different agents in the economy to facilitate exposition. Compared with previous literature, however, this paper allows for heterogenous firms that interact in the market for intermediate goods as producers and consumers of materials used as inputs of production. In what follows, we present the full model for completeness, but readers familiar with the literature may want to concentrate on Section 2.2.1, which contains our modeling contribution, and skip the more standard elements of the model.

## 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. Thus, the survival rate of bankers is $\gamma$. 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 consider the maximization problem of a representative household with preferences,

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

where $\beta \in (0,1)$ is the subjective discount factor, $C_t$ is final consumption, $h \in (0,1)$ measures the degree of habit formation, $L_{s,t}$ is labor supplied to firms in sector $s$, $\chi_s, \eta > 0$ are constant parameters, and $\mathbb{E}_0$ is the expectation conditional on information known at time $t = 0$. 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, $D_t$. Deposits pay a gross rate of return $R_t^D$. The household's budget constraint, expressed in nominal terms, 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, $\Xi$ is the startup transfer given to new bankers, $W_{s,t}$ is the wage in sector $s$, $T_t$ is a lump-sum tax or transfer, $\Pi_t$ is dividends received from all firms. Following the literature, the startup transfer given to new bankers is constant. $P_t$ serves as the model counterpart of the consumer price index (CPI) and is formally defined below (see (13)).

## 2.2 Production

### 2.2.1 Goods-producing Firms

The representative firm in sector $s \in S$ produces output $\mathcal{Y}_{s,t}$ using the production function,[1]

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

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 $s$, $L_{s,t}$ 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 parameters that satisfy the restriction $\alpha_s^L + \alpha_s^K + \alpha_s^M = 1$. Productivity shocks follow AR(1) processes

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

for $s = 1, 2, \ldots, S$, where $\rho_A, \rho_s \in (-1,1)$ and $\epsilon_{A,t}$ and $\epsilon_{s,t}$ are independently and identically distributed (i.i.d.) innovations with mean zero and variances $\sigma_A^2$ and $\sigma_s^2$, respectively.

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

Materials is an aggregate of goods produced by all firms in all sectors,

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

where $m_{sj,t}$ is materials purchased from the representative firm in sector $j$, and $\xi_{sj}$ are weights that satisfy $\sum_{j=1}^{S} \xi_{sj} = 1$. 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

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

where $X_{s,t}$ denotes new purchases of physical capital goods. Similar to Carlstrom, Fuerst, and Paustian (2017), the firm faces an external funding constraint whereby it must finance a proportion of its investment with external funds obtained by selling long-term bonds. This constraint motivates the need for financial intermediation. As in Woodford (2001), bonds are perpetuities with decay parameter for coupon payments $\kappa \in [0, 1/\beta)$. That is, a unit of bond issued in period $t$ pays a coupon of $\kappa^{\tau}$ dollars $\tau+1$ periods later. Denoting the total nominal coupon liability in period $t$ that arises from all past issuances by $F_{s,t-1}$, one can show that new net bond issuances are $f_{s,t} - \kappa f_{s,t-1}/\pi_t$ where $f_{s,t} = F_{s,t}/P_t$ denotes the real liability. Then, the external funding constraint faced by the firm is

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

where $\psi_s \in (0,1)$ is the proportion of physical capital expenditures that must be externally financed, $p_t^X$ is the real price of a unit of physical capital, and $Q_{s,t}$ is the price of the bond issued by firm $s$. The proportion $\psi_s$ and the bond price may vary across sectors and, hence, are indexed by $s$. The "loan-in-advance" constraint in Carlstrom et al. (2017) is the special case of (6) where $\psi = 1$ and all investment must be externally financed.

The firm maximizes

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

where $\Lambda_{0,t}$ is the household's stochastic discount factor, $p_{s,t}$ is the real price of a unit of good $\mathcal{Y}_{s,t}$, $w_{s,t} = W_{s,t}/P_t$ is the real wage rate in sector $s$, and $p_{s,t}^M$ is the real price of the 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

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

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

$$m_{sj,t} = \xi_{sj} \left( \frac{p_{j,t}}{p_{s,t}^{M}} \right)^{-1} M_{s,t}. \tag{7}$$

### 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 output from the representative firm in its sector. Retailers pay the same price, $p_{s,t}$, as goods-producing firms that employ good $s$ 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,

$$\int_0^1 \mathcal{Y}_{s,t}(r) dr = \mathcal{Y}_{s,t} - \sum_{j=1}^{S} m_{js,t},$$

Retailer $r$ converts the undifferentiated good $\mathcal{Y}_{s,t}(r)$ into the differentiated good $Y_{s,t}(r)$ using a linear repackaging technology, $Y_{s,t}(r) = \mathcal{Y}_{s,t}(r)$. The retailer sells its differentiated goods to a sectoral aggregator at a retailer-specific nominal price $P_{s,t}(r)$. Product differentiation makes the retailer a monopolistic competitor that can chose its price. The retailer takes as given the demand for its differentiated good (see (9) below) and is subject to a nominal frictions that prevents it from adjusting its price in every period. We model these frictions as in Calvo (1983), with $\mu_s$ denoting the probability that the retailer will not be able to change its price in a given period. Then, the retailer maximizes

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

where 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 $\mu_s$. Profits earned by retailers are transferred to households as dividends and form part of $\Pi_t$ 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. The representative sectoral aggregator uses the technology

$$Y_{s,t} = \left( \int_0^1 Y_{s,t}(r)^{(\zeta_s - 1)/\zeta_s} dr \right)^{\zeta_s/(\zeta_s - 1)}, \tag{8}$$

where $Y_{s,t}$ is output and $\zeta_s > 1$ is the sector-specific elasticity of substitution. The sectoral aggregator maximizes

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

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 that will be taken as given by the retailer,

$$Y_{s,t}(r) = \left( \frac{P_{s,t}(r)}{P_{s,t}} \right)^{-\zeta_s} Y_{s,t}, \tag{9}$$

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

$$P_{s,t} = \left( \int_0^1 P_{s,t}(r)^{1-\zeta_s} dr \right)^{1/(1-\zeta_s)}. \tag{10}$$

#### 2.2.4 Final-output Aggregators

Final-output aggregators are perfectly competitive firms that purchase output from all sectoral aggregators and combine them into a final good that can be consumed by households and the government, or turned into capital by capital-good producers. The representative final-output aggregator uses the technology

$$Y_t = \prod_{s=1}^{S} (\varsigma_s)^{-\varsigma_s} (Y_{s,t})^{\varsigma_s} \tag{11}$$

where $\varsigma_s$ are aggregation weights that satisfy $\sum_{s=1}^{S} \varsigma_s = 1$. The final-output aggregator maximizes

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

subject to (11), 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

$$Y_{s,t} = \varsigma_s P_t Y_t / P_{s,t}, \tag{12}$$

where the aggregate price index is,

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

### 2.2.5 Capital-good Producers

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

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

The nominal price of the input $I_t$ is $P_t$, which is also the price of a unit of final consumption, and 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 $\Pi_t$ in (2).

## 2.3 Financial Intermediaries

Financial intermediaries transfer resources between households and goods-producing firms acting as both investment and commercial banks. The representative financial intermediary indexed by $i \in [0, 1]$ can allocate its own wealth and deposits obtained from households among privately-issued bonds, $F_{s,t}(i)$, government-issued bonds, $B_t(i)$, and interest-bearing reserves $E_t(i)$ 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. The balance sheet of intermediary $i$ is

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

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

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

where $R^F_{s,t}$, $R^B_t$, and $R^E_t$ are the gross nominal rates of return on private bonds issued by firm $s$, 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.

The objective of the banker that operates the financial intermediary is to maximize expected terminal net wealth,

$$V_t(i) = \max(1-\gamma)\mathbb{E}_t \sum_{\tau=1}^{\infty} \gamma^{\tau-1} \Lambda_{t,t+\tau} n_{t+\tau}(i), \tag{18}$$

where $n_t(i) = N(i)/P_t$. As in Gertler and Karadi (2011), the intermediary could divert funds to her own household rather than to finance firms' capital projects and only a fraction of those funds could be recovered by depositors with the intermediary able to keep the unrecovered 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,

$$V_t(i) \geq \theta_t \left( \sum_{s=1}^{S} \theta_s Q_{s,t} f_{s,t}(i) + \theta_b Q_{b,t} b_t(i) \right), \tag{19}$$

where right-hand side are the assets that banker could abscond with, $b_t(i) = B_t(i)/P_t$, $\theta_t$ is an stochastic term, $\theta_s, \theta_b \in (0,1)$ are constant parameters such that $\theta_b < \theta_s$ for all $s$ denoting the fact that recovering private assets may be more difficult than recovering government bonds. Since $\theta_s$ varies across sectors, the risk premium varies across sectors as well in manner that satisfies

$$\mathbb{E}_t \left( \frac{R^F_{s,t+1} - R^D_t}{R^F_{j,t+1} - R^D_t} \right) = \frac{\theta_s}{\theta_j}, \tag{20}$$

for any two sectors $s$ and $j$. There is no agency problem concerning reserves held at the central bank and they are fully recoverable in case of default. This implies that $R^E_t = R^D_t$ and there is no risk premium associated with the holding of reserves in (17).

The term $\theta_t$ may be interpreted as a systemic credit risk. An increase in $\theta_t$ means that the intermediary would get to keep a larger proportion of all diverted funds, but this then reduces the amount depositors are willing to lend. It is assumed that $\theta_t$ follows the 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 variance $\sigma^2_\theta$.

## 2.4 The Government

### 2.4.1 Fiscal Authority

The government finances its expenditures, $G_t$, 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. That is,

$$P_t G_t = T_t + Z_t + Q_{b,t}(B_t - \kappa B_{t-1}) - B_{t-1}. \tag{21}$$

Government expenditure follows the exogenous AR(1) process

$$\ln G_t = (1 - \rho_G) \ln G + \rho_G \ln G_{t-1} + \epsilon_{G,t}, \tag{22}$$

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 variance $\sigma_G^2$. Following the literature, it is assumed that the government levies the required taxes, $T_t$, to ensure that its intertemporal budget constraint is satisfied.

### 2.4.2 Central Bank

In normal times the central bank sets the short-term (one-period) policy rate, $R_t$, following the Taylor-type rule,

$$\ln R_t = (1 - \rho_R) \ln R + \rho_R \ln R_{t-1} + (1 - \rho_R) \left(\lambda_\pi \ln(\pi_t/\pi) + \lambda_y \ln\left(Y_t/Y_{t-1}\right)\right) + \epsilon_{R,t}, \tag{23}$$

where $\rho_R \in (0, 1)$ represents interest-rate smoothing, $R$ is the steady state value of the policy rate, $\pi$ is the inflation target, $\lambda_\pi$ and $\lambda_y$ are policy parameters, and $\epsilon_{R,t}$ is an i.i.d. disturbance with mean zero and variance $\sigma_R^2$. The policy rate is subject to a zero-lower bound (ZLB). Above the ZLB,

$$R_t^D = R_t^E = R_t,$$

with $R_t$ given by (23).

In times of crisis, after the interest rate has been cut to its ZLB—so that $\ln R_t = 0$ 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 central bank's sheet is

$$\sum_{s=1}^{S} Q_{s,t} F_{s,t}^c + Q_{b,t} B_t^c = E_t, \tag{24}$$

where $F^c_{s,t}$ and $B^c_t$ denote the central bank holdings of private bonds issued by firm $s$ and public bonds, respectively. We assume that purchases follow the autoregressive processes

$$f^c_{s,t} = (1-\rho_F) f^c_s + \rho_F f^c_{s,t-1} + \epsilon_{F,s,t}, \tag{25}$$

$$b^c_t = (1-\rho_B) b^c + \rho^B b^c_{t-1} + \epsilon_{B,t}, \tag{26}$$

where $f^c_s$ and $b^c$ are the steady values of central bank bonds holdings, $\rho_F, \rho_B \in (-1,1)$, and $\epsilon_{F,s,t}$ and $\epsilon_{B,t}$ are i.i.d. disturbances with zero mean and variances $\sigma^2_{F,s}$ and $\sigma^2_B$. Central bank bond purchases change the composition of the financial intermediaries' balance sheet, increasing their holdings of interest-bearing reserves and decreasing their bond holdings. Since the former are fully recoverable in case of default while the latter are not, QE relaxes the incentive constraint (19) leading to an increase in lending to firms and investment.

### 2.5 Equilibrium and Model Solution

In equilibrium, the markets for labor, capital goods, government bonds, and private bonds clear, that is $L_t = \sum_{s=1}^S L_{s,t}$, $X_t = \sum_{s=1}^S X_{s,t}$, $B_t = \int_0^1 B_t(i)di + B^c_t$, $F_{s,t} = \int_0^1 F_{s,t}(i)di + F^c_{s,t}$, for $s = 1, ..., S$. Substituting out the dividends from firms ($\Pi_t$), the net worth of exiting bankers (net of transfers to new bankers), and the lump-sum tax or transfer ($T_t$) from the government budget constraint (21) into (2) deliver the aggregate resource constraint,

$$C_t + I_t + G_t = Y_t. \tag{27}$$

Since the model does not have a closed-form solution, we use a first-order perturbation to approximate the model dynamics around the deterministic steady, where the ZLB does not bind. In experiments where the ZLB binds, we use the piece-wise linear approximation proposed by Guerreri and Iacoviello (2015) to solve the model. Guerreri and Iacoviello show that this approach is as accurate as global solution method, but much faster computationally.

## 3. 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 manufacturing ($s = 1$) 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

The parameters of the production functions are estimated following Bouakez, Cardia, and Ruge-Murcia (2009) using the sectoral input-output database (KLEM) produced by Dale Jorgenson.[2] 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, manufacturing consists of 27 sectors and includes all manufacturing, agriculture, mining, and construction. Services consists of 8 sectors and includes all services and government enterprises. The first-order conditions that describe the optimal choice of labor and materials imply

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

where $p_{s,t}^M M_{s,t} = \sum_{j=1}^{S} p_{j,t} m_{sj,t}$. 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 $\alpha_s^L$ and $\alpha_s^M$ 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 $\alpha_s^K = 1 - \alpha_s^L - \alpha_s^M$.

Final estimates of the production function parameters are the sample averages of the yearly estimates and their standard deviations are $\sqrt{\sigma^2/T}$ where $T = 46$ is the sample size and $\sigma^2$ is the variance of the yearly observations. 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

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). 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. 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 $\xi_{sj}$

[2] The data are available at http://scholar.harvard.edu/jorgenson/data and are described in Jorgenson and Stiroh (2000).

of the I-O table.[3] Note that the first-order condition (7) implies

$$\xi_{sj} = \frac{m_{sj,t} p_{j,t}}{M_{s,t} p^M_{s,t}}. \tag{28}$$

Thus, the weight $\xi_{sj}$ is simply the proportion of total expenditures in materials by 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 (28) as the weighted sum of good purchases from sector $j$.

We use the 15-industry I-O tables and include agriculture, mining, and construction in the manufacturing sector. The procedure described above delivers estimates of $\xi_{sj}$ for each year. The final estimate of $\xi_{sj}$ is the sample average for the period 1997 to 2019 with standard deviations $\sqrt{\sigma^2/T}$ where $T = 23$ is the sample size and $\sigma^2$ is the variance of the yearly observations. These figures 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 manufacturing firms and vice-versa.

### 3.3 Other 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 and we focus on the zero-inflation steady state. The subjective discount rate ($\beta$) is set to 0.995, which implies a steady-state real interest rate of 2% at the annual rate. The habit formation parameter ($h$) is set 0.80. The weights of the disutility of labor in the utility function ($\chi_1$ and $\chi_2$) are set so that the labor ratio of services to manufacturing is 4.69. This ratio was computed using the series "All Employees" of service-providing industries and goods-producing industries in the Current Employment Statistics produced by the Bureau of Labor Statistics (BLS). The figure 4.69 is the sample mean of the seasonally-adjusted monthly data from 1997 to 2019.

The curvature parameter of the labor disutility ($\eta$) is set to 0.276, which is the value used by Gertler and Karadi (2011, 2013). The survival probability of financial intermediaries is 0.95, meaning that their expected horizon is 5 years. 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

[3] 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.

of assets to aggregate net worth) of 4, as in Gertler and Karadi (2011, 2013). This value of $\Xi$ represents only 2.1% of the net worth of financial intermediaries in steady state, which is about 6.

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 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 capital that can be diverted by the intermediary is $\theta = 0.579$. We then normalize $\theta_s$ to 1 in both sectors and set $\theta_b = 1/3$. This means that the intermediary could divert the full 0.579 from private assets, but only $0.579 \cdot (1/3) = 0.193$ from public assets. The parameter $\psi_s$ is set to 0.81 based on work by Zetlin-Jones and Shourideh (2017) who find that private firms use external funding to finance about 80% of their investments. To explore the role of heterogeneity in agency costs and financing constraints and their interaction with other forms of heterogeneity in the model, we consider experiments where $\theta_s = 0.8$ in one sector and $\theta_s = 1$ in the other, and experiments where $\psi_s = 0.405$ in one other sector while $\theta_s = 0.81$ in the other. 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 $\varsigma_s$ 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 (12) 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 manufacturing and 12 months in services. 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 ($\rho_R$) 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 autoregressive coefficients of government expenditure ($\rho_G$) and all productivity shocks ($\rho_A, \rho_1$, and $\rho_2$) are set to 0.95, the autoregressive coefficient of the credit shock ($\rho_\theta$) is set to 0.98, and autoregressive coefficients of central bank asset purchases ($\rho_F$ and $\rho_B$) are set to 0.80.

The value of the standard deviation of the shocks are inconsequential for the impulse-response analysis that we pursue in the following sections because the linear solution of the model is certainty-equivalent. The same applies to the piece-wise linear solution obtained using the method proposed by Guerreri and Iacoviello (2015), which assumes that the system returns to the reference regime in finite time and agents expect that no future shocks will occur. For this reason we simply normalize all standard deviations to 0.01, except for $\sigma_\theta$, which is set to 0.04. Since this shock is used to model a financial crisis that takes the economy to the zero lower-bound, using a large standard deviation for $\theta_t$ is helpful.

# 4. Quantitative Analysis

This section reports results from policy experiments that examine the effects of central bank asset purchases when the economy is at the zero lower bound and further interest rate cuts are not feasible. The experiments take the following form. First, as previous literature, we assume that a negative shock takes the economy to the zero lower bound. In our case, this shock is an increase in the systemic credit risk ($\theta_t$). Second, after the economy has been at the zero lower bound for six periods, the central bank implements a quantitative easing program. We consider three policies, namely, purchases of government bonds, purchases of bonds issued by firms in manufacturing, and purchases of bonds issued by firms in services. The size of the purchases increases the central bank's balance sheet by about 4% of quarterly GDP.

Finally, we compute nonlinear impulse responses (see Gallant, Rossi, and Tauchen, 1993, and Koop, Pesaran, and Potter, 1996) defined as the difference between the path of the variables under the QE policy and under no policy. In the latter case, the economy would eventually return to its steady state on its own. Thus, put differently, impulse responses quantify the effects of the QE policy compared with doing nothing. In addition to the benchmark calibration, experiments are also conducted under alternative specifications to help us understand the aggregate and sectoral effects of different asset purchases.

## 4.1 Symmetric Model

As starting point, we consider a version of the model where both sectors are identical and the economy is at the zero lower bound. The input-output matrix is the identity matrix and, thus, there are no sectoral interactions in the market for materials because each sector uses only its own good as materials input. The production function parameters are the same in both sectors and are computed as in section 3.1 but using total aggregate, rather than sectoral, expenditures so that $\alpha^L = 0.33$, $\alpha^M = 0.50$, and $\alpha^K = 0.17$. Price rigidity is $\mu_1 = \mu_2 = 0.333$, meaning that all prices are fixed on average for 1.5 quarters. Sectors are heterogeneous in their relative size but this is not crucial for the impulse responses, which plot variables in deviations from their steady state.

Results are reported in Figure 2 where the horizontal axis represents quarters and the vertical axis is the percentage deviation from the deterministic steady state. Results from this calibration replicate those reported elsewhere in the literature for the one-sector economy, with our two sectors behaving identically because there is no sectoral heterogeneity. By purchasing bonds and undertaking financial intermediation, the central bank sidesteps the incentive constraint faced by private banks, reduces bond yields in both sectors, and facilitates investment by goods-producing firms. This mechanism differs from the one in standard New Keynesian models where conventional monetary policy affects the intertemporal price of consumption. Instead, unconventional monetary policy here affects the economy through investment by increasing the funding available to firms and reducing the price at which they can borrow. Evidence supporting this mechanism is reported by Foley-Fisher, Ramcharan, and Yu (2016) and Koetter (2020). Foley-Fisher, Ramcharan, and Yu find that the Maturity Extension Program of the U.S. Federal Reserve decreased the bond market risk premia and relaxed financial constraints for some firms. Koetter (2020) finds that the Securities Markets Program of the ECB induced German private banks to increase their commercial, government, and foreign lending, but to decrease retail (mortgage) lending. In Figure 2, both sectors increase their physical capital and, thus, aggregate investment and aggregate output increase, along with sectoral output and hours worked. Wages increase initially and after a brief period of overshooting return to their steady state from above. Inflation increases substantially but relative prices are unaffected because price rigidity is the same in both sectors. The QE policy is clearly expansionary but its effect is moderated by the increase in their real price of capital goods which curbs demand.

As it is known from earlier literature, private bond purchases initially have larger effects than government bond purchases.[4] The reason is that private bonds are less attractive than public bonds in terms of the incentive constraint (19) and, thus, require a larger premium to induce financial intermediaries to hold them (that is, $R^F_{s,t} > R^B_t > R^D_t$). Bond purchases by the central bank reduce the premium that firms must pay to borrow and, in some sense, relax the constraint that limits their investment. Since the premium is lower for government bonds, a dollar purchase of government bonds has a weaker effect on excess returns than a dollar purchase of private bonds. The expansionary effect on output and investment lasts for about seven quarters after which these variables go below their long-run value and return to their steady state from below. This overshooting is larger for private than for public bonds and primarily due to the deleveraging by firms, which eventually

[4] See, for example, the discussion in Gertler and Karadi (2013, p. 22)

face increased coupon payments. The finding that private bonds are more expansionary than public bonds in the short-run, but potentially contractionary in the medium run, means that the former may not dominate the latter as the best object of central bank purchases in a QE program.

### 4.2 Benchmark Calibration

Figure 3 reports the effects of central bank asset purchases under the benchmark calibration. Sectors differ in production functions and price rigidity (see Tables 1 and 3, respectively) and the input-output table is that in Table 2. Aggregate effects are similar to those reported in the symmetric case, but there are substantial differences in the effects of the QE policy across sectors. The heterogeneity in sectoral responses is driven primarily by the heterogeneity in price rigidity.[5] The intuition is that the heterogeneity in production functions and input-output at this level of disaggregation is limited. Although the production function parameters in Table 1 are statistically different across sectors, their quantitative difference is small. And, although the off-diagonal elements in the input-output table are non-negligible, they are quantitatively similar to each other and smaller than the diagonal elements. In contrast, the quantitative difference in price rigidity is large (see Table 3).

Following the expansionary monetary policy, firms in the more flexible price sector (manufacturing) raise their prices and their relative price increases, while firms in the more rigid price sector (services) see their relative price decrease. Since the demand of sectoral good $s$ by the final-good producer is decreasing in its relative price, the increase in relative price limits the output expansion in manufacturing, which is about one-fourth of that in services at its peak. For this reason, the increases in hours worked and wages are also smaller in manufacturing than in services. The capital stock in manufacturing decreases initially, but it eventually increases and reachers a proportion similar to that in services.

Under the benchmark calibration, the effects of bond purchases from manufacturing and services are the same at all horizons and are larger than the effects of government bond purchases initially. The reason is simply that under the non-arbitrage condition (20), excess returns are proportional only to agency costs. Since $\theta_1/\theta_2 = 1$ in this calibration, bonds from manufacturing and services are perfect substitutes. (We relax this parameterization below). Since $\theta_1/\theta_b = \theta_2/\theta_b = 3$ in this calibration, meaning that agency costs are larger for private bonds than for government bonds, a dollar purchases of private bonds has a larger effect on excess returns than a dollar purchase of government bonds. However, Figure 3 shows that the effect of private bonds become contractionary as firms deleverage when faced with increased coupon payments in the medium run.

[5] This claim is based on unreported experiments where we examined individually each form of heterogeneity. These results are available from the authors upon request.

The comovement of sectoral output following QE is driven by the input-output structure. On the one hand, as pointed above, the increase in relative price unambiguously leads to a decrease in the demand of goods from manufacturing by the final-good producer (see (12)). On the other hand, the increase in output in the service sector induces an increase in the demand of goods from manufacturing to be used as inputs in production. The net effect is positive so that output in both sectors increases following the expansionary monetary policy. Put differently, without an input-output structure, sectoral output would move in opposite directions after the monetary policy shock solely from the effects of the policy on relative prices. In related research, Bouakez, Cardia, and Ruge-Murcia (2011) and Sudo (2012) examine the role of sectoral interactions in solving the comovement puzzle when the price of durable goods is less rigid than the price of nondurable goods. These authors show that in a multi-sector New Keynesian model the increase demand for capital goods on the part of the more rigid-price sector after an expansionary interest rate shock leads an increase in output in all sectors.

### 4.3 Higher Agency Costs in Services

We now relax the assumption that agency costs are the same in both sectors and assume instead $\theta_1 = 0.8$ and $\theta_2 = 1$, while keeping all other parameters as in the benchmark calibration. This means that the fraction of capital that the intermediary can diverted from private bonds in manufacturing is $0.579 \cdot 0.8 = 0.463$, while the fraction that she can divert from private bonds in services is 0.579. In turn, this implies that the spread between private bonds from manufacturing and government bonds is 240 basis points, while the spread between private bonds from services and government bonds is 300 basis points. Results are reported in Figure 4.

In this case, a dollar purchase of private bonds from services has a larger effect than a dollar purchase of private bonds from manufacturing, which in turn has a larger effect than a dollar purchase of government bonds. As before, the reason is that the incentive constraint is tighter for bonds from services and, thus, financial intermediation by the central bank is more effective when undertaken via purchases of these bonds. However, the deleveraging effect is also larger for bonds from services. Figure 4 shows that both aggregate investment and aggregate output increase, but the magnitude of their increases is smaller than under the benchmark calibration because the overall investment constraint is lower and, hence, the QE policy is less expansionary. Inflation increases by more, and the price of capital by less, than under the benchmark calibration.

The key results in Figure 4 is that the QE policy tend to benefit the most the sector with higher agency costs and amplifies the effects of heterogeneity in price rigidity. The increase (resp. decrease) in the relative price of the good from manufacturing (resp. services) is more pronounced than under the benchmark calibration. Thus, the decrease in the demand of goods from manufacturing by the final-good producer overcomes the increased demand by services, and output in manufacturing decreases while that in services increases. The decrease in the supply of goods from manufacturing exacerbates the increase in their relative price. There is a large increase in investment in services and a decrease in manufacturing, but hours worked increase in both sectors. There is also a mild initial decrease in wages in both sectors, but then they increase rapidly and return to their steady state from above.

## 4.4 Higher Financing Constraints in Services

We now consider the case where the proportion of investment that must be financed by external funds in services is higher than that in manufacturing. That is, $\psi_1 = 0.405$ in manufacturing, while $\theta_s = 0.81$ in services, meaning that firms in manufacturing use external funding to finance about 40.5% of their investments and firms in services use 81%. All other parameters are as in the benchmark calibration except for $\theta_1 = 0.8$ and $\theta_2 = 1$ as in the previous experiment. This means that services has both higher agency costs and needs for external financing than manufacturing. Results are reported in Figure 5.

The qualitative effects of QE in this case are similar to those reported in Figure 4, but there are substantial quantitative differences. In particular, the effect of QE on aggregate output, aggregate investment, and the price of capital is smaller and the effect on inflation larger. At the sectoral level, the heterogeneity in financing constraints, in addition to that in agency costs, amplifies further the heterogeneity in price rigidity. The stock of capital increases by more, and the relative price decreases by more, in services compared with Figure 4. In contrast, the stock of capital decreases by more, and the relative price increases by more, in manufacturing compared with Figure 4. Hence, the difference in sectoral effects is magnified in this case.

## 4.5 Higher Agency Costs in Manufacturing

We now consider the converse case where agency costs are higher in manufacturing. Thus, we set $\theta_1 = 1$ and $\theta_2 = 0.8$, and keep all other parameters as in the benchmark calibration. These values imply that the spread between private bonds from manufacturing and government bonds is 300 basis points, while the spread between private bonds from services and government bonds is 240 basis points. Results are reported in Figure 6.

Aggregate effects are similar to those in the benchmark calibration, except that inflation features a delayed increase to the QE policy. The basic mechanism, whereby price rigidity is key to the heterogeneity in sectoral responses is still present in this experiment, but the dynamics are different from those in Figure 4 where services has the higher agency costs. In both figures the relative price of goods produced by manufacturing increase because its prices are more flexible than those produced in services. However, in Figure 4 the full increase is delayed by one period, while in Figure 6, the full effect takes place in the first period and is followed by a sharp decrease. The converse is true for the relative price of goods produced by services. The largest difference between the scenarios considered in Figures 4 and 6 concerns sectoral investment. In the former case investment in services increases, while in the latter case decreases, while the converse is true for manufacturing. Notice, however, that hours and wages increase in both sectors.

### 4.6 Higher Financing Constraints in Manufacturing

Finally, we now consider the case where the proportion of investment that must be financed by external funds in manufacturing is higher than that in services. That is, $\psi_1 = 0.81$ in manufacturing, while $\theta_s = 0.405$ in services. This means that firms in services use external funding to finance about 40.5% of their investments while firms in manufacturing use 81%. All other parameters are as in the benchmark calibration except for $\theta_1 = 1$ and $\theta_2 = 0.8$ as in the previous experiment. Thus, manufacturing features both higher agency costs and needs for external financing than services. Results are reported in Figure 7.

Compared with Figure 6, the effect of QE on aggregate output, aggregate investment, and the price of capital is smaller, and the inflation dynamics involve an initial drop followed by a sharp increase. At the sectoral level, the heterogeneity in financing constraints, in addition to that in agency costs, amplifies further the heterogeneity in price rigidity. The sectoral effects of the QE policy are qualitatively similar to those in Figure 6, but the relative magnitudes are larger. The effects on the stock of capital and relative price are larger in absolute value compared with Figure 6. The dynamics of hours worked and wages are similar in both figures and with limited quantitative differences.

## 5. Conclusions

This paper examines quantitative easing in an economy with heterogenous production sectors and asks whether different bond purchases may have different sectoral and aggregate effects. We depart from earlier literature in allowing sectors to have different price rigidity, production function, and agency costs, and permit their interaction in the market for intermediate goods in the spirit of the literature on production networks. Results show aggregate results are generally unaffected by heterogeneity at the sectoral level. However, quantitative easing induces very different responses across sectors with a non-trivial interaction between price rigidity and agency costs. We also find that at this coarse level of disaggregation, the quantitative effect of heterogeneity in production functions and input-output is limited and we provide an explanation for this result. In future work, we intend to explore further the welfare implications of different asset purchases by the central bank.

**Table 1. Production Function Parameters**

| | $\alpha^L$ | | $\alpha^M$ | | $\alpha^K$ | |
|---|---|---|---|---|---|---|
| Sector | Estimate | s.e. | Estimate | s.e. | Estimate | s.e. |
| Manufacturing | 0.278* | 0.012 | 0.597* | 0.011 | 0.125* | 0.013 |
| Services | 0.395* | 0.011 | 0.387* | 0.014 | 0.218* | 0.007 |

*Note:* The table reports estimates of the production function parameters, s.e. denotes standard errors, and the superscript $*$ denotes statistical significance at the 5% level.

**Table 2. Input-Output Linkages**

| | Consumer | | | |
|---|---|---|---|---|
| | Manufacturing | | Services | |
| Producer | Estimate | s.e. | Estimate | s.e. |
| Manufacturing | 0.678* | 0.021 | 0.195* | 0.015 |
| Services | 0.322* | 0.021 | 0.805* | 0.015 |

*Note:* The table reports estimates of the production aggregation weights computed using the U.S. Input-Output tables. See notes to Table 1.

**Table 3. Calibrated Parameters**

| Parameter | Value or Target | Description |
|---|---|---|
| $\beta$ | 0.995 | Subjective discount rate |
| $h$ | 0.815 | Habit formation parameter |
| $\eta$ | 0.276 | Inverse Frisch elasticity of labor supply |
| $\chi$ | 3.482 | Labor disutility |
| $\gamma$ | 0.95 | Survival rate of financial intermediary |
| $\Xi$ | 0.125 | Transfer to new intermediaries |
| $\kappa$ | $1 - 1/40$ | Decay parameter for bond coupon payments |
| $\theta$ | 0.579 | Fraction of total capital that can be diverted by intermediary |
| $\theta_s$ | 1 | Recoverability parameter for private bonds |
| $\theta_b$ | 1/3 | Recoverability parameter for government bonds |
| $\psi_s$ | 0.81 | Fraction of investment externally financed |
| $\delta$ | 0.025 | Depreciation rate |
| $\phi$ | 2 | Parameter in investment cost function |
| $\varsigma_1$ | 0.212 | Output share of manufacturing |
| $\varsigma_2$ | 0.788 | Output share of services |
| $\zeta$ | 8 | Elasticity of substitution |
| $\mu_1$ | 0.25 | Probability of no price adjustment in manufacturing |
| $\mu_2$ | 0.75 | Probability of no price adjustment in services |
| $b$ | 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 |
| $f_b$ | 0.06 | Central bank steady state holdings of public bonds |
| $\rho_R$ | 0.80 | Interest-rate smoothing |
| $\lambda_\pi$ | 1.50 | Inflation coefficient in Taylor rule |
| $\lambda_y$ | 0.25 | Output coefficient in Taylor rule |
| $\sigma_R$ | 0.01 | Standard deviation |
| $\rho_\theta$ | 0.98 | AR coefficient of systemic credit shock |
| $\sigma_\theta$ | 0.04 | Standard deviation of systemic credit shock |
| $\rho_A$ | 0.95 | AR coefficient of aggregate productivity shock |
| $\sigma_A$ | 0.01 | Standard deviation |
| $\rho_s$ | 0.95 | AR coefficient of sectoral productivity shock |
| $\sigma_s$ | 0.01 | Standard deviation |
| $\rho_F$ | 0.80 | Smoothing of private-sector bond purchases |
| $\sigma_{Fs}$ | 0.01 | Standard deviation |
| $\rho_B$ | 0.80 | Smoothing of government bond purchases |
| $\sigma_B$ | 0.01 | Standard deviation |
| $\rho_G$ | 0.95 | AR coefficient government expenditure |
| $\sigma_G$ | 0.01 | Standard deviation |

*Note:* The table reports the parameters used to calibrate the model.

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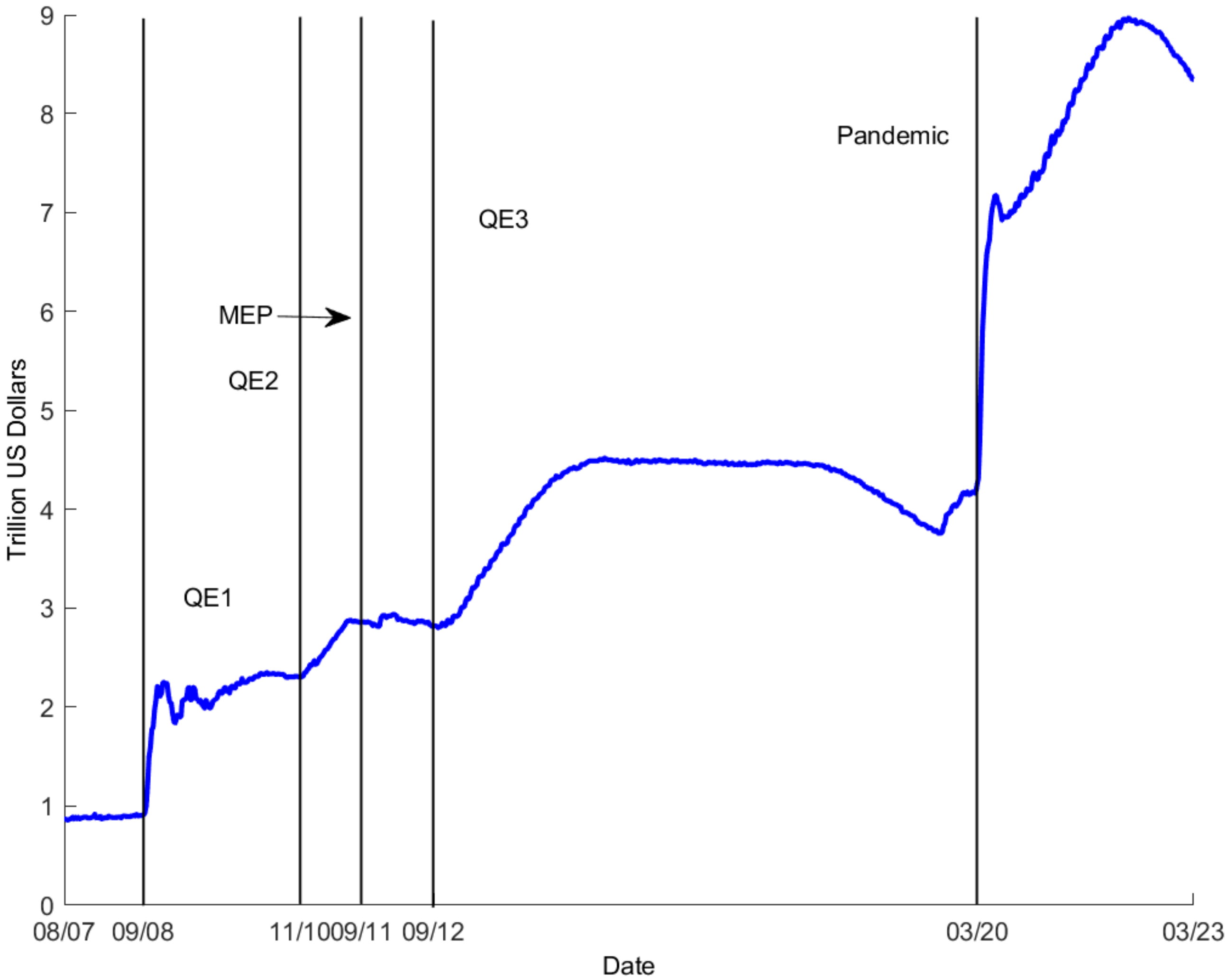
Figure 1: Federal Reserve Balance Sheet



# Figure 2: Symmetric Calibration

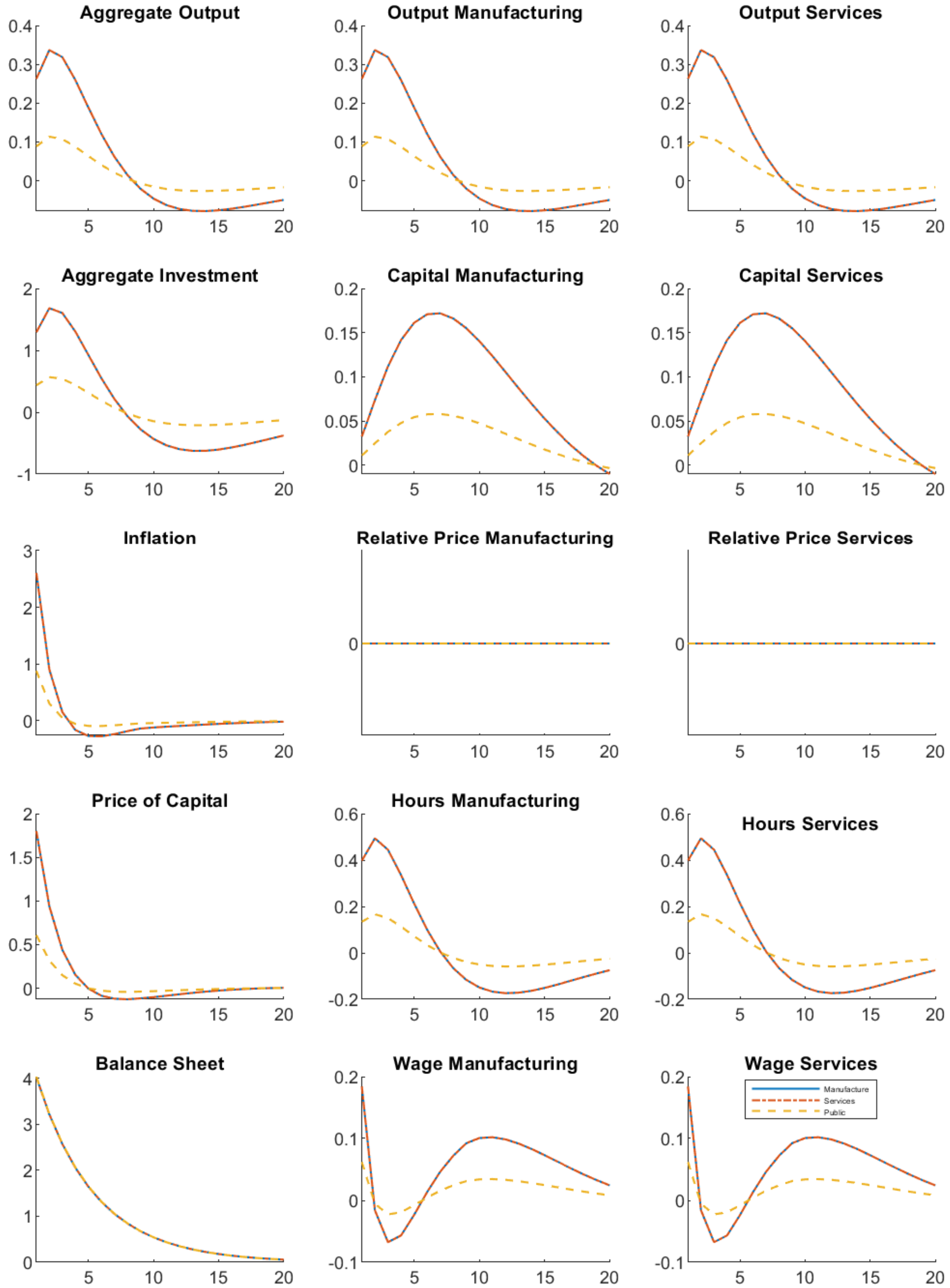


Figure 3: Benchmark Calibration

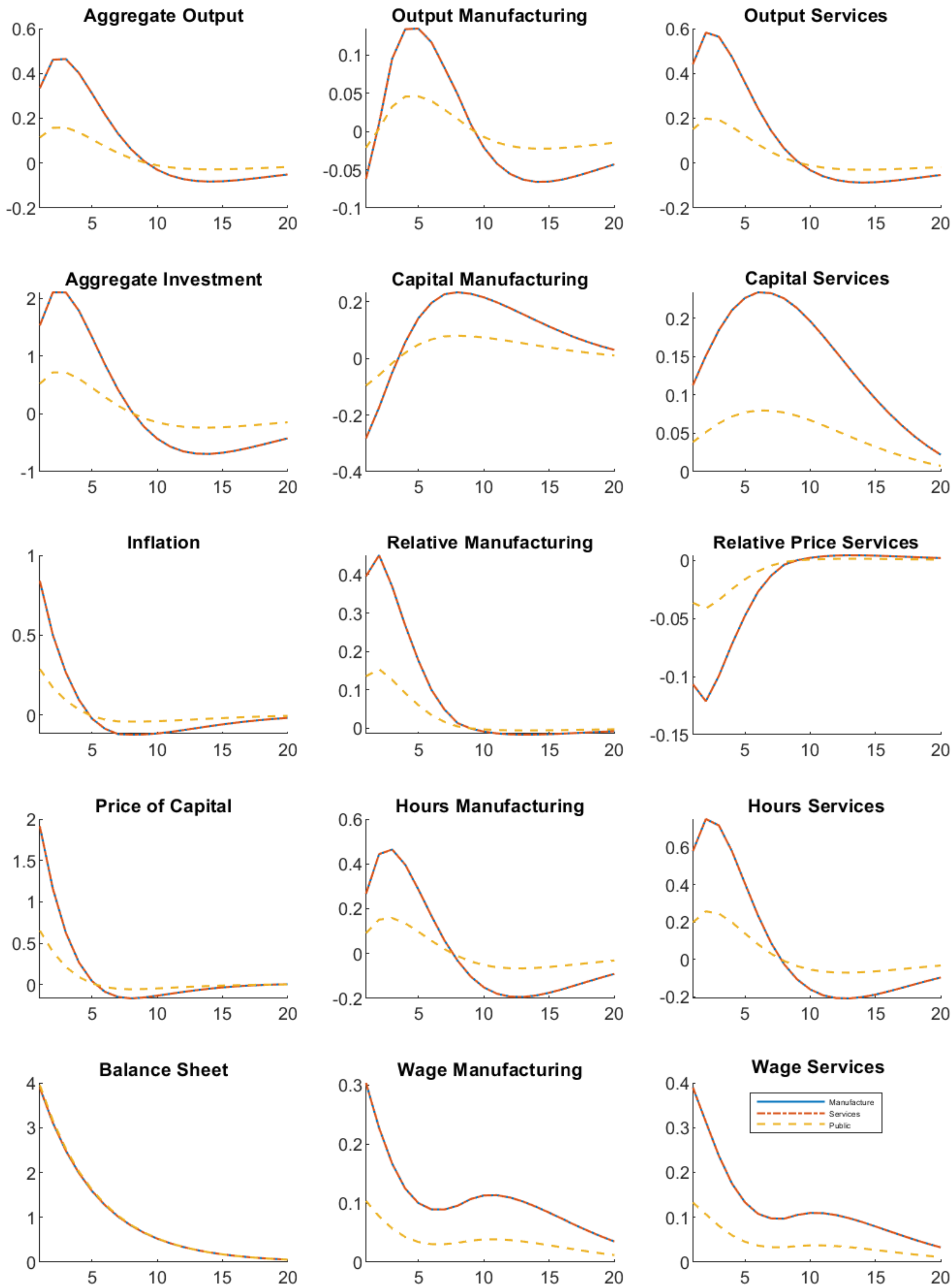


Figure 4: Higher Agency Costs in Services

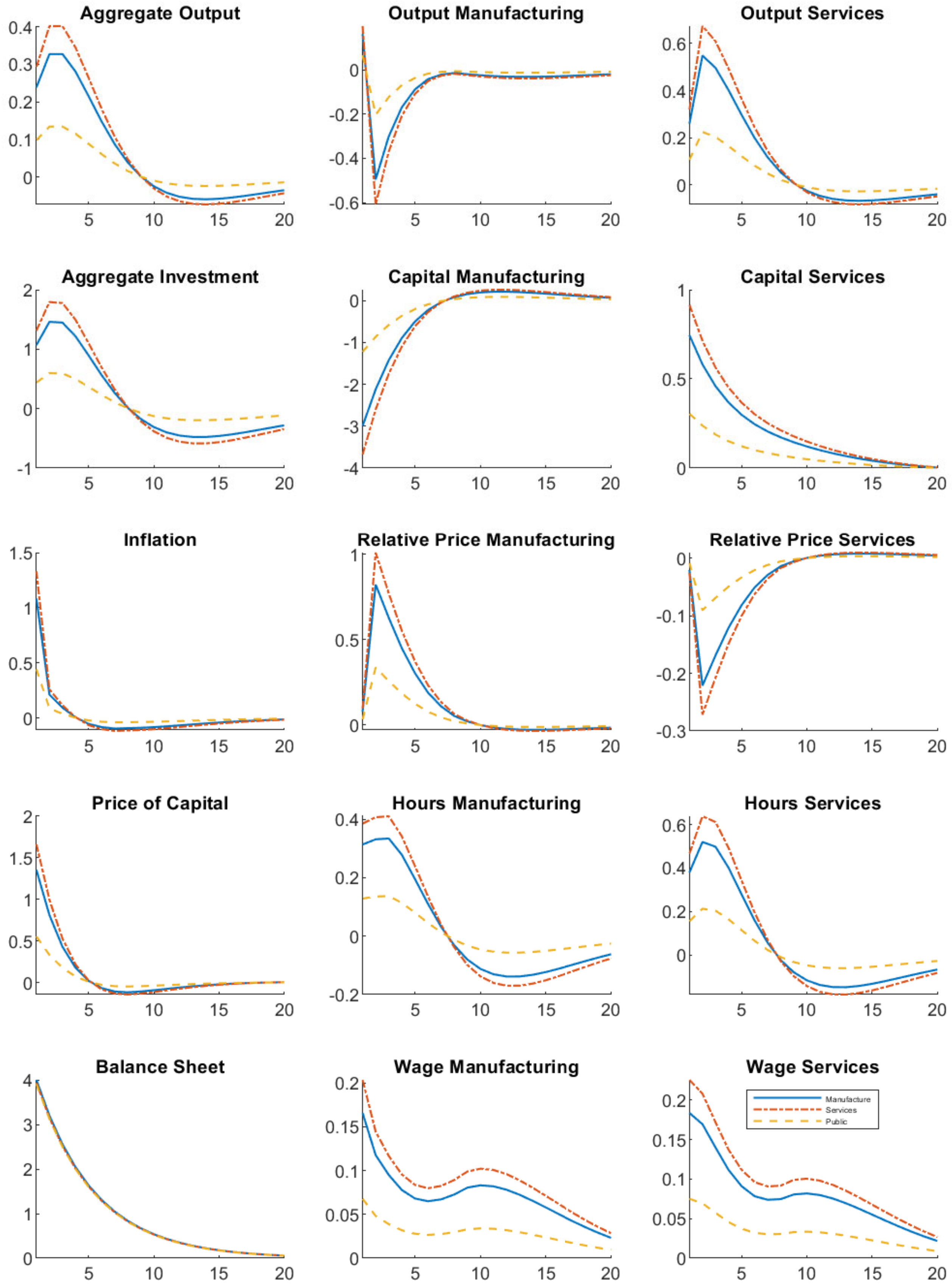
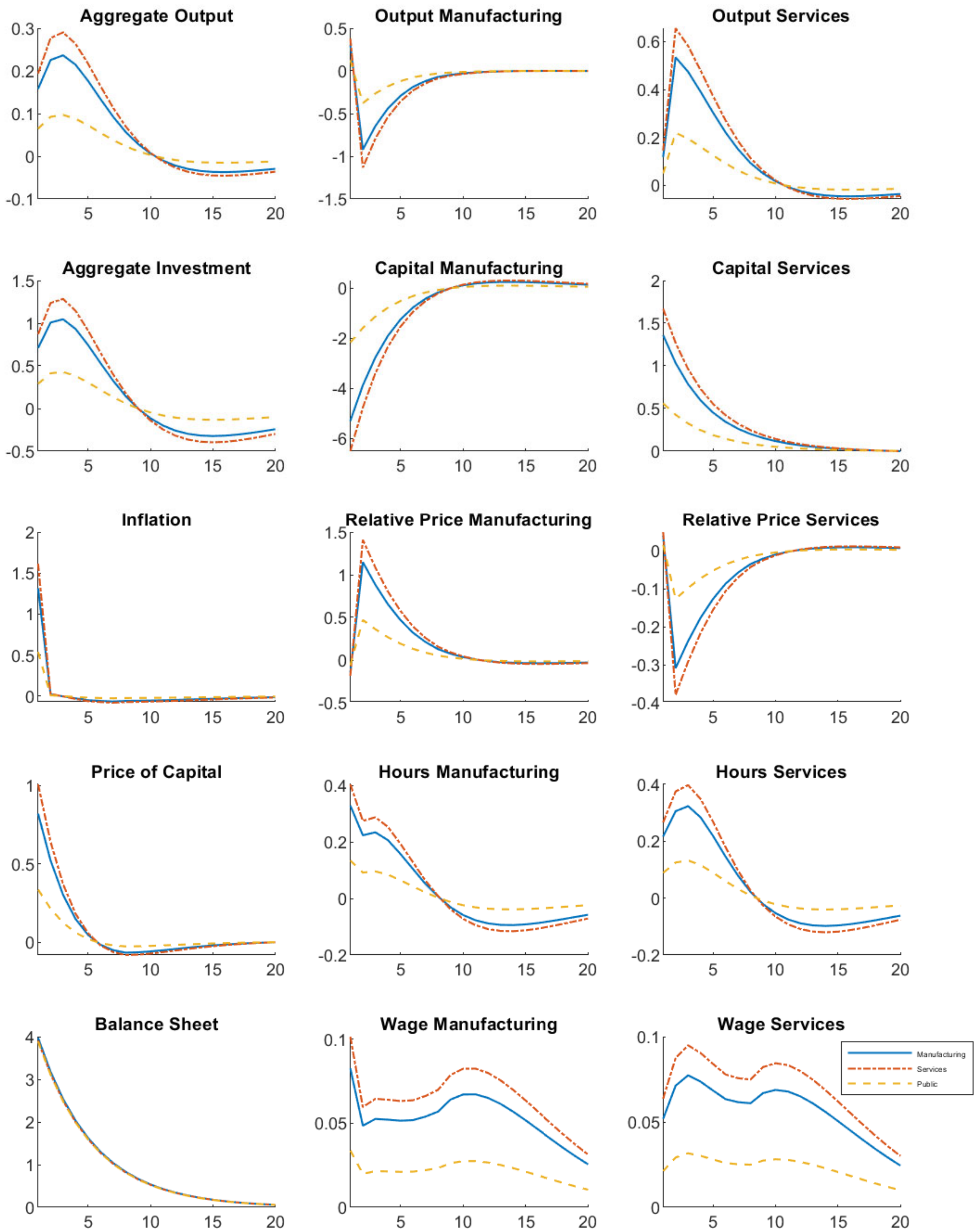


Figure 5: Higher Agency Costs and Financing Constraints in Services



# Figure 6: Higher Agency Costs in Manufacturing

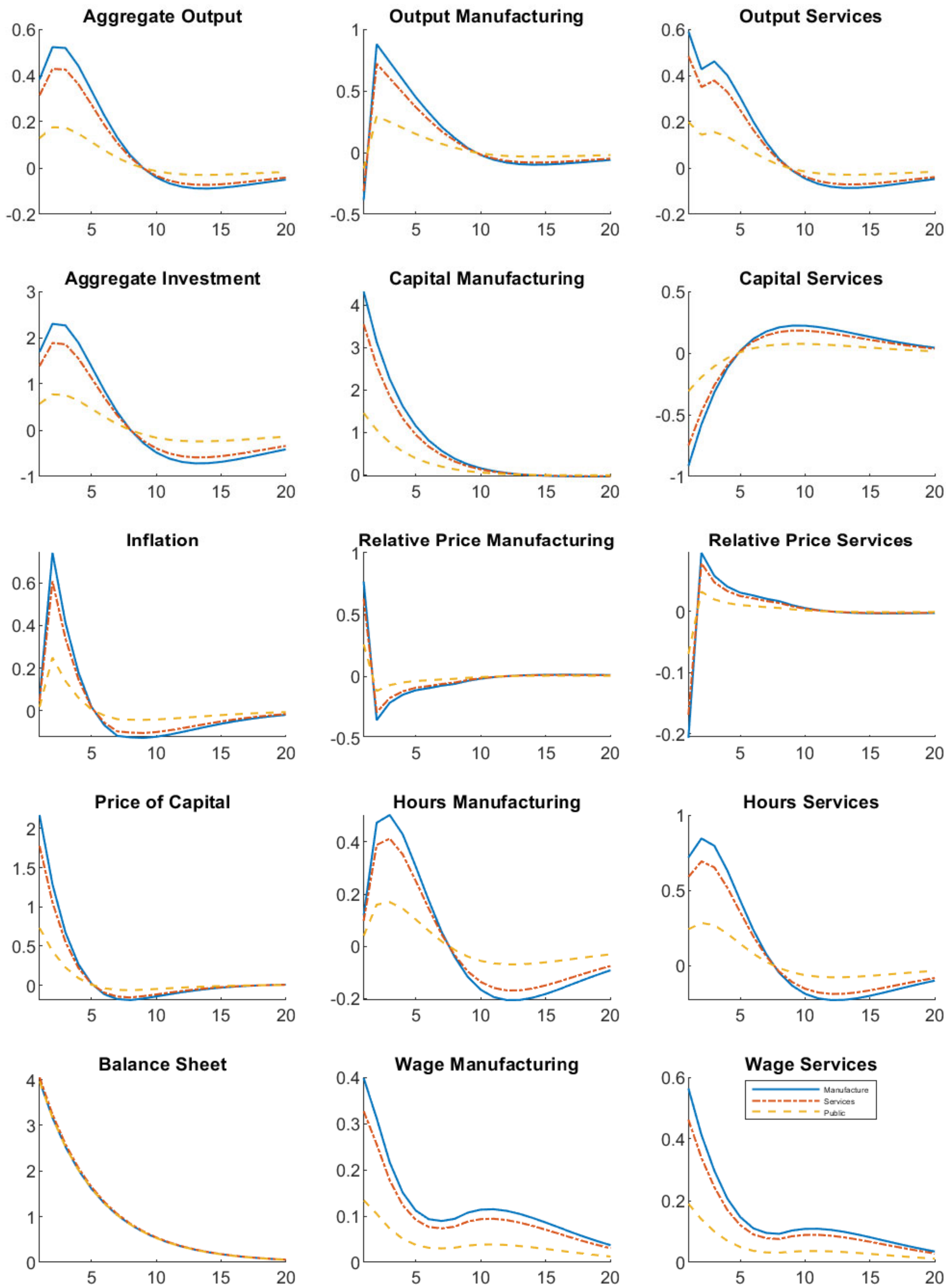


Figure 7: Higher Agency Costs and Financing Constraints in Manufacturing