The Building Blocks of Inflation: The role of monetary policy and the gap between goods and services

Sacha Gelfer*

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Abstract

I build and estimate a three-region structural macroeconomic model with a goods, services, housing and oil sector. The model also has meaningful household portfolio decisions over foreign and domestic bond holdings and financial intermediation to investigate the efficacy of large-scale asset purchases (LSAP) by a central bank. The model is built and estimated to ensure that the potential causes that have been pointed to as a reason for the global inflation seen in the COVID recovery economy are accounted for. Examining the dynamics of the model, LSAPs conducted in an economy with relative high demand for goods rather than services will lead to a bigger expansionary and inflationary impact than in an economy where demand for services is relatively higher than goods. I also find that LSAPs are more expansionary and inflationary when the service sector is incurring supply shocks. These findings help us understand why LSAPs conducted in the global financial crisis had such a different impact than those conducted in the COVID economy.

Keywords: Goods and Service Sectors, Unconventional Monetary Policy, International Bond Portfolio, DSGE, Oil and the Business Cycle, Financial Accelerator, Housing Sector
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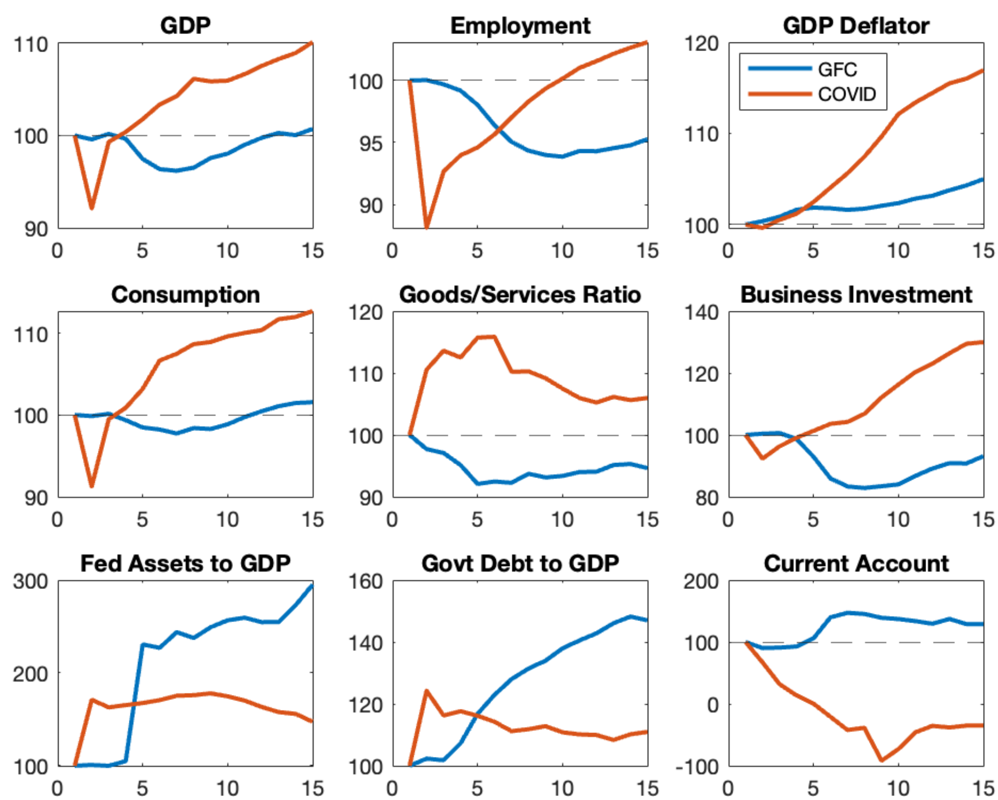
*Bentley University, Waltham, MA, USA. E-mail address: sgelfer@bentley.edu

1 Introduction

In the past two decades the world economy has endured two major events, the global financial crisis (GFC) and the global pandemic (COVID). Comparing the two episodes points to a few similarities and differences in the dynamics that occurred in the surrounding 3.5 years of each crisis. Figure 1 illustrates this by normalizing different US times series to be 100 at 2007Q4 for the GFC and 2020Q1 for COVID. In both crises the global economy shrunk significantly and short-term interest rates in the US and other countries approached the zero lower bound (ZLB). Due to this, central banks around the world turned to unconventional monetary policies such as large-scale asset purchases (LSAP) to stimulate the economy by lowering long-term interest rates. Further, large expansionary fiscal policy was conducted in both episodes, significantly increasing federal public debt to GDP levels.

Figure 1: Global Financial Crisis (GFC) vs COVID Economies



Notes: The solid blue line plots the various US time series indexed to100 at 2007Q4 while the red line plots the same US time series indexed to 100 at 2020Q1.

Beyond the output contraction and the policy response few similarities remain between the two episodes. The GFC was marked by a prolonged decline in employment, consumption, and business investment, a shift away from goods and towards services consumption, a rise in the current account, and low, stable inflation. In contrast, the COVID economy saw rapid rebounds in employment, consumption, and investment, a surge in goods consumption relative to services, a decline in the current account, and inflation levels not seen in over four decades.

This paper develops a multi-sector, three-region, open-economy New Keynesian DSGE model to account for these contrasting dynamics and theoretically evaluates if LSAPs are more expansionary/inflationary under certain concurrent sectoral supply and demand imbalances. The model is then used to empirically evaluate the main drivers of inflation in the COVID recovery economy. In particular, the model is able to shed light on eight key story lines that are pointed to as main drivers of the recent inflation episode. These include monetary policy, fiscal expenditures and transfers, consumer demand shift from services to goods, supply shocks in the services sector, oil supply disruptions, increase in housing demand, international supply chain disruptions and asset price inflation.

The paper's analysis assigns an important role to all of these but most notably I find that unconventional monetary policy is the largest factor in driving overall inflation and investment in the COVID recovery economy. This is due to the fact that I find that unconventional monetary policy is most expansionary in real and nominal terms when many in the above list are occurring in a certain direction. For example, unconventional monetary policy increases output and inflation most when relative demand is higher in the goods sector, when supply shocks are higher in the service sector, when assets have high demand and when fiscal transfers are occurring. These are all scenarios that occurred during the COVID economy, while the opposite occurred during the GFC economy. As a result the model is able to explain the discrepancies seen in Figure 1 and highlights why similar monetary policy conducted in both episodes triggered such different trajectories for prices, international trade and the macroeconomy in their aftermath. Thus, the central finding of the paper is that the impacts of unconventional monetary policy can differ when interacting with other macroeconomic conditions many of which were seen in 2020-21 but not during the GFC.

The paper's model features tradable goods, non-tradable services, and a housing sector, each subject to sector-specific supply and demand shocks. It incorporates international bond portfolios, enabling analysis of both conventional and unconventional monetary policy, as well as fiscal expenditures and transfers, an endogenous oil market and global financial linkages. Given its detail, the model is able to evaluate the potential heterogeneous effects of LSAP when sectoral demand and supply might be relatively larger in one sector. Given the rich data used in estimating the model, it is able to quantify the relative importance of the different drivers of real variables and inflation in the US and the rest of the world (ROW) over the last 20 years.

The detailed features of the model rely on distinctive characteristics associated with the goods, services and housing sectors. The goods sector is modeled to allow for international trade and relies on labor, capital (created from both domestic and international investment), intermediate goods (both domestic and international) and oil as production factors, the service sector produces non-tradable services that rely on labor, intermediate domestic services, intermediate goods (both domestic and international) and oil as production factors and the housing sector relies on the factors of labor, land and the existing housing stock. Each sector is associated with nominal frictions in price setting and wage setting creating different dynamics in each when aggregate or sectoral shocks occur.

The inclusion of 61 international data sets used in estimating the model allows us to empirically dissect the baseline model and other models nested inside of it. I find that the baseline model is best at matching key empirical moments and co-movements with the most important modeling feature being the need for a separate goods and services production/consumption sector.

Related Literature

The paper contributes to several strands of literature. The first main strand of literature focuses on modeling the international impact of COVID-19 and its economic aftermath in a structural framework. Multi-sector open-economy modeling techniques have been found to be important in explaining the international dynamics that have occurred over the last 15 years. Bobasu et al. (2019) showed how the correlation of international trade and GDP has weakened while the correlation between international trade and manufacturing production has increased. Further, Kilian and Zhou (2018) showed the importance that modeling the commodity sector has on replicating the economic dynamics of exchange rates, energy prices and international trade over the past decade. Earlier work by Rabanal and Tuesta (2013) showed how a non-tradable sector was important in capturing the dynamics between the exchange rate and productivity shocks for the US and the EU. More recent work by Guerrieri et al. (2022) and Corrado et al. (2021) show the importance of multi-sector models and their cross-sector linkages have on explaining the COVID economy and recovery. Cardani et al. (2023) also evaluates COVID specific shocks for the US and Euro Area in a general equilibrium model with multi-stage production. These papers, like mine, show how sectoral and aggregate shocks interact with one another.

In addition to open-economy, multi-sector, production inputs, my paper also incorporates the literature on open-economy conventional and unconventional monetary policy evaluation. This paper builds on the models of Alpanda and Kabaca (2020), Gelfer and Gibbs (2023), Fornaro and Romei (2023) and Bianchi and Coulibaly (2024) who evaluated the domestic impact and international spillovers of conventional and endogenous unconventional monetary policy. These papers find that financial linkage between the regions is key in understanding the predominant empirical effects of unconventional monetary policy. In this paper unconventional monetary policy is also endogenously introduced but in a multi-sector model which is estimated using a rich amount of data.

My paper also compliments the literature that focuses on modeling the oil sector in an open-economy framework. Khalil (2022) develops a multi-region multi-sector model with an endogenous oil region. Khalil (2022) was motivated by Nakov and Nuno (2013) who showed the importance in modeling above ground oil inventory and Bergholt et al. (2019), who study the business cycle of a modeled oil-exporting economy. Gagliardone and Gertler (2023) incorporated an exogenous oil component into the domestic firm production process and found it to have a significant role in the post COVID macroeconomy for the US. My paper adds to the literature by incorporating all these techniques into one model. Of note, my paper finds a much smaller role for oil shocks in creating inflation as is seen in Gagliardone and Gertler (2023). Much of the producer cost inflation seen in my model is attributed into sectoral mark-up shocks and sectoral demand shocks instead, a result in line with Kilian and

Zhou (2022).

Finally, my paper fits into the growing literature studying and assigning cause to the post COVID inflation surge seen around the globe. My main contribution of this literature is related to the rich structure of the paper's model. It is able to include the important story line of relative demand of goods and services as a cause of inflation. In particular, relative demand shocks, shifting consumption demand from services towards goods, is assigned a large proportion of the rise in U.S. inflation in Baqaee and Farhi (2022), Alessandria et al. (2023), and Gagliardone and Gertler (2023). Further, the roles of fiscal policy, fiscal transfers and accommodating monetary policy are included in the paper's model which di Giovanni et al. (2023) and Gagliardone and Gertler (2023) attribute to a large portion of the inflation increase.

My paper contributes to these different strands of the structural modeling literature by incorporating the use of an open-economy multi-sector model with tradable and non-tradable output with production that includes international intermediate factors, a modeled endogenous oil producing region and a modeled international portfolio that encompasses unconventional monetary policy, financial markets and government transfers through the debt market. The rich structure of my model estimated with many observable variables allows for a deep analysis of the drivers of the international economy since before and during the global financial crisis as well as the before, during and post COVID periods. Most notably the developed model allows us to understand why similar policy conducted during the GFC and COVID economies could have had such different effects as seen in Figure 1. This is because the model has the structural detail to explain the COVID and post COVID economy while still capturing the economic dynamics seen before 2020.

In short, the paper's main contribution lies in its ability to reconcile the differential impact of LSAPs across crises by embedding them in a richly detailed, empirically grounded model that captures the connection between sectoral dynamics, international trade, fiscal policy and global financial conditions.

The remainder of the paper is organized as follows. Section 2 lays out the multi-sector, multi-region open-economy DSGE model. Section 3 describes the data used to estimate and calibrate the model along with the prior and posterior estimates of the model. Section 4 examines the moments of the estimated model and it also compares the dynamics associated with a large menu of shocks included in the model. Section 5 examines the heterogenous macroeconomic effects LSAPs can have depending on the current state of the economy. Section 5.1 looks at what is driving the larger state-dependent impact of unconventional monetary policy finding by looking at these effects using parameter sensitivity analysis. Section 6 presents historical shock decompositions for various macro-financial variables of the model to illustrate the large impact unconventional monetary policy had after COVID on inflation and trade. Section 7 summarizes and concludes.

2 Model

In this section, I augment a two-region open-economy DSGE model that includes rigidities and portfolio balance effects with a private credit market and financial accelerator detailed in Gelfer and Gibbs (2023) in four major ways. First, consumption is divided into two types, tradable goods and non-tradable services. Second, goods production and service production include sector specific labor, capital, intermediate inputs and oil nested into a CES production process. Third, an oil dominant economy is introduced as a third region into the model as described in Khalil (2022). Finally, a housing sector with housing capital is implemented into the model. Each region in the model includes households, financial intermediaries, entrepreneurs, capital producers, goods produces, service producers, housing producers, intermediate and wholesale domestic firms, importers, as well as fiscal and monetary policy rules.

The model features various nominal and real rigidities including sectoral-domestic price, import price and sectoral-wage stickiness, indexation of prices and wages, habit formation in consumption and housing, adjustment costs in investment, and costs of capital utilization. These features are included in standard closed and open-economy New Keynesian DSGE models (Smets and Wouters, (2007), Adolfson et al. (2007) Justiniano and Preston, (2010)). In addition, the model incorporates financial frictions with the inclusion of financial intermediaries that allocate household deposits in the form of risky loans to entrepreneurs who rent and purchase capital to domestic good producers and capital producers. Shocks to the financial sector are assumed to be correlated across regions. Households in each of the dominant two regions can hold domestic and foreign government bonds of both short and long-term duration subject to imperfect substitutability among the four types of risk-free bonds. The international bond portfolios held by households provide a channel for us to discuss the impact of synchronized global monetary policy.

I focus our discussion on the households' optimization problem, the production sectors, fiscal and monetary policy, and the trade aspects of the model. These features are important for understanding the transmission of LSAPs under different states of the world. The description of more features of the model, such as the financial sector, oil dominant region and employment, are relegated to online Appendix A1. I describe the agents in the domestic economy below, but the foreign economy (ROW) is analogous in our set-up. When variables from the foreign economy are introduced, I denote them with an $(^*)$ superscript.

2.1 Households

Households supply household-specific and sector-specific labor to employment agencies. Households maximize a CRRA utility function over an infinite horizon with additively separable utility in consumption, housing capital, assets, deposits and leisure. Households are subject to an exogenous preference shock that can be viewed as a shock in the consumer's consumption and saving decisions. In addition, households are subject to housing demand shocks and bond demand shocks that alter their preference for domestic to foreign bond ratio and short to long-term bond duration ratio.

There is a continuum of households indexed by j. The objective function for household j is given by:

$$E_t \sum_{s=0}^{\infty} \beta^s \Big[e_{b,t+s}\, log(c_{t+s}(j) - hc_{t+s-1}) + e_{hou_d,t+s}\, log(hou_{t+s}(j) - h_{hou} hou_{t+s-1}) + \\ \xi_a log(a_{t+s}(j)) + \xi_d log(dep_{t+s}(j)) - \frac{\xi_L (L_{t+s}(j))^{1+\nu_l}}{1+\nu_l} \Big] \qquad (1)$$

where $c_t(j)$ is real personal final consumption, $hou_t(j)$ is the real housing stock, $a_t(j)$ is the bond portfolio, $dep_t(j)$ are real deposits held with the financial intermediary and $L_t(j)$ is supply of a household differentiated type of aggregate labor. β is the time discount parameter, h and h_{hou} are identical parameters across households that capture consumption and housing persistence and ξ_a, ξ_d, and ξ_L are parameters that determine the relative importance of the bond portfolio, liquid deposits and labor in the utility function, respectively. All parameters not indexed by j are assumed to be identical across all households. Households face stochastic shocks $e_{b,t}$ and $e_{hou_d,t}$ that can be viewed as a utility preference shock for personal consumption and housing stock.

I assume personal consumption is made up of both final goods and final services. I impose imperfect substitution over consumption goods and consumption services using a CES structure. Personal consumption c_t, is a CES aggregate consisting of consumption goods, $c_{goods,t}$, and consumption services, $c_{serv,t}$:

$$c_t(j) = \left[(1-\gamma_{serv,c})^{\frac{1}{\lambda_{type}}} c_{goods,t}(j)^{\frac{\lambda_{type}-1}{\lambda_{type}}} + \gamma_{serv,c}^{\frac{1}{\lambda_{type}}} c_{serv,t}(j)^{\frac{\lambda_{type}-1}{\lambda_{type}}} \right]^{\frac{\lambda_{type}}{\lambda_{type}-1}} \tag{2}$$

where $\gamma_{serv,c}$ determines the share of services in personal consumption and λ_{type} is the elasticity of substitution between consumption goods and services.

In addition to a CES aggregator for consumption there is also a CES aggregator for aggregate Labor L_t:

$$L_t(j) = \left[(1-\gamma_{serv}-\Delta_{hou}) L_{goods,t}(j)^{1+\eta_l} + \gamma_{serv} L_{serv,t}(j)^{1+\eta_l} + \Delta_{hou} L_{hou,t}(j)^{1+\eta_l} \right]^{\frac{1}{1+\eta_l}} \tag{3}$$

where γ_{serv} and Δ_{hou} determine the share of services and housing in total production and η_l is the elasticity of substitution of labor supplied in services, goods and housing.

The wage of an individual type of worker, j, in industry jj, is given by $W_{jj,t(j)}$. Individual types of workers face adjustment costs when changing their nominal wage. Note that this preference specification implies that the demand for an individual type of worker is given by

$$L_{jj,t}(j) = \left(\frac{W_{jj,t}(j)}{W_{jj,t}} \right)^{-\Theta_{w,jj,t}} L_{jj,t} \tag{4}$$

where $W_{jj,t}$ is the nominal wage rate in sector jj and $\Theta_{w,jj,t}$ is a time-varying elasticity of substitution between the differentiated labor in sector jj. Wage cost-push shocks $e_{w,jj,t}$ are centered around the markup of wages over the marginal rate of substitution, $\theta_{w,jj}$ in each sector jj.

As in Alpanda and Kabaca (2020) I assume imperfect substitution inside the asset portfolio for government bonds in order to capture the liquidity benefits generated by these assets, as well as financial institutions' portfolio preferences across the different types of government bonds. I impose imperfect substitution over different maturities and currencies using a nested CES structure. The bond portfolio in the utility function, a_t, is a CES aggregate consisting of short-term government bonds, $a_{S,t}$, and long-term government bonds, $a_{L,t}$:

$$a_t(j) = \left[\gamma_{a,t}^{\frac{1}{\lambda_a}} a_{S,t}(j)^{\frac{\lambda_a - 1}{\lambda_a}} + (1 - \gamma_{a,t})^{\frac{1}{\lambda_a}} a_{L,t}(j)^{\frac{\lambda_a - 1}{\lambda_a}} \right]^{\frac{\lambda_a}{\lambda_a - 1}} \tag{5}$$

where $\gamma_{a,t}$ determines the share of short-term bonds in the aggregate portfolio, and λ_a is the elasticity of substitution between short and long-term bonds. $\gamma_{a,t}$ is an exogenous process, centered around γ_a, and can be thought of as a preference demand shock for short term bonds.

In addition to duration diversification, the bond portfolio is also subject to a subportfolio for short-term domestic bonds, $B_{H,S,t}$ and foreign bonds, $B_{F,S,t}$. The CES aggregator for this subportfolio is given by:

$$a_{S,t}(j) = \left[\gamma_{S,t}^{\frac{1}{\lambda_S}} \left(\frac{B_{H,S,t}(j)}{P_t} \right)^{\frac{\lambda_S - 1}{\lambda_S}} + (1 - \gamma_{S,t})^{\frac{1}{\lambda_S}} \left(\frac{e_t B_{F,S,t}(j)}{P_t} \right)^{\frac{\lambda_S - 1}{\lambda_S}} \right]^{\frac{\lambda_S}{\lambda_S - 1}} \tag{6}$$

where $\gamma_{S,t}$ determines the share of short-term domestic bonds in the subaggregate portfolio and λ_s is the elasticity of substitution between domestic and foreign short-term bonds. $\gamma_{S,t}$ is an exogenous process, centered around γ_S, and can be thought of as a preference demand shock for domestic short term bonds relative to foreign short-term bonds. P_t is the aggregate price level and e_t is the nominal exchange rate in terms of domestic currency per unit of foreign currency.

The long-term subportfolio is subject to a similar CES set-up between long-term domestic government bonds, $q_{L,t}B_{H,L,t}$ and long-term foreign government bonds, $q_L^*B_{F,L,t}$.

$$a_{L,t}(j) = \left[\gamma_{L,t}^{\frac{1}{\lambda_L}}\left(\frac{q_{L,t}B_{H,L,t}(j)}{P_t}\right)^{\frac{\lambda_L-1}{\lambda_L}} + (1-\gamma_{L,t})^{\frac{1}{\lambda_L}}\left(\frac{e_t q_{L,t}^* B_{F,L,t}(j)}{P_t}\right)^{\frac{\lambda_L-1}{\lambda_L}}\right]^{\frac{\lambda_L}{\lambda_L-1}} \tag{7}$$

where $\gamma_{L,t}$ and λ_L govern the share of domestic bonds in the subportfolio and the elasticity of substitution between domestic and foreign long-term bonds. $q_{L,t}$ is the relative price for domestic long-term bonds and along with κ determines the long-term yield[1] , $R_{L,t}$.

$$R_{L,t} = \frac{1}{q_{L,t}} + \kappa \tag{8}$$

Household j's budget constraint is:

$$\begin{aligned}
c_t(j) + \frac{P_{Hou,t}HI_t(j)}{P_t} + \frac{Dep_t(j)}{P_t} + \frac{B_{H,S,t}(j)}{P_t} + \frac{e_t B_{F,S,t}(j)}{P_t} + \frac{q_{L,t}B_{H,L,t}(j)}{P_t} + \frac{e_t q_{L,t}^* B_{F,L,t}(j)}{P_t} \leq \\
\frac{W_{goods,t}(j)}{P_t}L_{goods,t}(j) + \frac{W_{serv,t}(j)}{P_t}L_{serv,t}(j) + \frac{W_{hou,t}(j)}{P_t}L_{hou,t}(j) + \frac{R_{l,t}Land}{P_t} + \\
\frac{R_{t-1}^D Dep_{t-1}(j)}{P_t} + \frac{R_{t-1}B_{H,S,t-1}(j)}{P_t} + \frac{e_t R_{t-1}^* B_{F,S,t-1}(j)}{P_t} + \frac{R_{L,t}q_{L,t}B_{H,L,t-1}(j)}{P_t} + \\
\frac{e_t R_{L,t}^* q_{L,t}^* B_{F,L,t-1}(j)}{P_t} + \frac{\Pi_{serv,t}}{P_t} + \frac{\Pi_{hou,t}}{P_t} + \frac{\Pi_{H,t}}{P_t} + \frac{\Pi_{F,t}}{P_t} - \frac{Tax_t}{P_t} + Tr_t - \\
\sum_{jj=goods,serv,hou} \frac{\kappa_{w,jj}}{2}\left(\frac{W_{jj,t}(j)/W_{jj,t-1}(j)}{\pi_{w,jj,t-1}^{\iota_{w,jj}}\pi^{1-\iota_{w,jj}}} - 1\right)^2 \frac{W_{jj,t}}{P_t}L_{jj,t}
\end{aligned} \tag{9}$$

where $HI_t(j)$ is housing investment that adds to the level of the housing stock, $P_{Hou,t}$ is the price of housing, $Dep_t(j)$ is the amount of nominal deposits held with the financial institution, R_t is the nominal interest rate on short-run bonds, R_t^D and $R_{l,t}$ is the nominal interest rate financial intermediaries pay on deposits and the nominal interest rate paid to land owners in the housing sector. Π_{serv_t}, $\Pi_{hou_t}\Pi_{H_t}$ and Π_{F_t} are the profit households get from owning the intermediate domestic firms and importers, $W_{jj,t}(j)$ is the nominal wage earned in each jj sector. Tax_t are lump sum taxes payed to the government and Tr_t are wealth transfers to/from

[1] As in Woodford (2001), long-term bonds are modeled as perpetuities that pay a coupon payment of 1 unit in the first period after issuance, and their coupon payments decay by a factor of κ in each period after.

the entrepreneurial agents. Households supply market power heterogeneous labor in each sector and face quadratic adjustment costs when changing nominal wages in each sector, Rotemberg (1982). $\kappa_{w,jj}$ is an adjustment cost parameter in each sector, π is inflation and $\iota_{w,jj}$ determine the degree of indexation of wage adjustments to past inflation in each sector. Household j chooses $\{c_t(j), HI_t(j), dep_t(j), b_{H,S,t}(j), b_{H,L,t}(j), b_{F,S,t}(j), b_{F,L,t}(j), W_{goods,t}(j), W_{serv,t}(j),$ $W_{hou,t}(j) L_{goods,t}(j), L_{serv,t}(j), L_{hou,t}(j)\}_{t=0}^{\infty}$ that maximize expected utility (1) subject to the household budget constraint.

The first order conditions for consumption, housing stock, labor supply in sector jj, bank deposits, real short-term and long-term bonds foretell the interaction between unconventional monetary policy and aggregate demand.

$$\lambda_t = \frac{e_{b,t}}{c_t - hc_{t-1}} \tag{10}$$

$$\tag{11}$$

$$p_{hou,t}\lambda_t = \beta(1-\tau_{hou})E_t\left[p_{hou,t+1}\lambda_{t+1}\right] + \frac{e_{hou_d,t}}{hou_t - h_{hou}hou_{t-1}} \tag{12}$$

$$\tag{13}$$

$$\lambda_t = \frac{\xi_L L_t^{\nu_l-\eta_l}\gamma_{jj}L_{jj,t}^{\eta_l}}{(w_{jj,t}-\lambda_{w,jj,t})} \qquad for\, jj = \{goods, serv, hou\} \tag{14}$$

$$\tag{15}$$

$$\lambda_t = \beta E_t\left[\frac{R_t^D\lambda_{t+1}}{\pi_{t+1}}\right] + \frac{\xi_d}{dep_t} \tag{16}$$

$$\tag{17}$$

$$\lambda_t = \beta E_t\left[\frac{R_t\lambda_{t+1}}{\pi_{t+1}}\right] + \frac{\xi_a}{a_t}\frac{\partial a_t}{\partial a_{S,t}}\frac{\partial a_{S,t}}{\partial b_{H,S,t}} \tag{18}$$

$$\tag{19}$$

$$q_{L,t}\lambda_t = \beta E_t\left[\frac{R_{L,t+1}q_{L,t+1}\lambda_{t+1}}{\pi_{t+1}}\right] + \frac{\xi_a}{a_t}\frac{\partial a_t}{\partial a_{L,t}}\frac{\partial a_{L,t}}{\partial b_{H,L,t}} \tag{20}$$

Large-scale asset purchases of domestic long-term bonds by the monetary authority will alter marginal utility even if short-run interest rates remain constant. The change in marginal utility will directly effect consumption, housing demand, labor supply in each sector, and loan supply (bank deposits). Further, the first order conditions for domestic and foreign short-term bonds and domestic and foreign long-term bonds can be combined respectively and log linearized to produce short-term and long-term uncovered interest rate parity (UIP) conditions.

$$\hat{R}_t - \hat{R}^*_t = E_t\hat{d}_{t+1} + \left(\frac{\pi}{\beta R} - 1\right)\frac{1}{\lambda_s}\left[\hat{b}_{H,S,t} - (\hat{rer}_t + \hat{b}_{F,S,t}) - \frac{1}{1-\gamma_S}\hat{\gamma}_{S,t}\right] \tag{21}$$

$$\begin{aligned}\hat{R}_{L,t} - \hat{R}^*_{L,t} = \frac{\kappa}{R_L}\left(E_t[\hat{R}_{L,t+1}] - E_t[\hat{R}^*_{L,t+1}]\right) + \left(1 - \frac{\kappa}{R_L}\right)\Big\{E_t\hat{d}_{t+1} + \\ \left(\frac{\pi}{\beta R} - 1\right)\frac{1}{\lambda_L}\left[\hat{q}_{L,t} + \hat{b}_{H,L,t} - (\hat{rer}_t + \hat{q}^*_{L,t} + \hat{b}_{F,L,t}) - \frac{1}{1-\gamma_L}\hat{\gamma}_{L,t}\right]\Big\}\end{aligned} \tag{22}$$

The two UIP conditions demonstrate additional aggregate demand effects of unconventional monetary policy by directly impacting the real exchange rate and thus, net export demand in the tradable goods sector. In the above equations $\hat{rer}_t$ is the real exchange rate ($\hat{rer}_t = \hat{e}_t\hat{P}^*_t/\hat{P}_t$) and $\hat{d}_t$ is the the nominal depreciation of the domestic currency ($\hat{d}_t = \hat{e}_t - \hat{e}_{t-1}$). It is clear by the short-term UIP condition that unconventional monetary policy affects the current and expected exchange rate even if the interest rate differential between the two areas does not change. The degree of this change will depend on the substitutability of domestic and foreign short-run bonds, λ_s. A similar story is true in regard to the long-run UIP. [2] Given that the real exchange rate has a direct effect on the tradable goods sector and imported oil prices, the current model structure allows us to account for possible transmission mechanisms of unconventional monetary policy that have not been examined in the structural macroeconomic literature thus far.

2.2 Intermediate Producing Sectors

Intermediate good producers are the first stage of production. Intermediate firms use utilized capital, labor packaged by the employment agencies, other intermediate input goods and oil to produce differentiated intermediate goods that they sell to the final goods producers. A continuum of these firms indexed by i exist and use the following CES technology

[2] The effect of domestic unconventional monetary policy in regard to the long-term UIP condition is ambiguous. Its direction and magnitude depends on the long-term interest rate differential that will occur after large-scale asset purchases. This differential will heavily depend on the estimates of λ_a and λ^*_a, as well as the values of λ_L, γ_L and γ^*_L. The estimates of this paper for all these parameters imply that the long-term interest rate differential would decrease after a large-scale asset purchase and that the relative change would be smaller than the decrease in domestic long-term bonds held by the public; thus, the long-term UIP condition amplifies a current depreciation and future appreciation of the domestic currency as in Gelfer and Gibbs (2023).

production process:

$$y_{goods,t}(i) = e_{a,goods,t}\Bigg[(1-\alpha_K-\alpha_{O,goods}-\alpha_{M,goods})^{\frac{1}{\tau_{goods}}} L_{goods,t}^{\frac{\tau_{goods}-1}{\tau_{goods}}} + \alpha_{O,goods}^{\frac{1}{\tau_{goods}}} Oil_{goods,t}^{\frac{\tau_{goods}-1}{\tau_{goods}}} + \alpha_K^{\frac{1}{\tau_{goods}}} K_t^{\frac{\tau_{goods}-1}{\tau_{goods}}} + \alpha_{M,goods}^{\frac{1}{\tau_{goods}}} Int_{goods,t}^{\frac{\tau_{goods}-1}{\tau_{goods}}}\Bigg]^{\frac{\tau_{goods}}{\tau_{goods}-1}} \tag{23}$$

where K_t is utilized capital[3], $Oil_{goods,t}$ is the oil factor of production by the domestic goods sector, $Int_{goods,t}$ is the bundle of domestic and foreign intermediate input goods used in production and $e_{a,goods,t}$ is a stationary stochastic productivity shock that alters the production process. τ_{goods} denotes the elasticity of substitution between the factor inputs in the goods sector.

The intermediate firms' profit in the domestic goods sector at time t is given by:

$$\frac{\Pi_{H,t}(i)}{P_t} = \frac{P_{H,t}(i)}{P_t} y_{goods,t}(i) - \frac{W_{goods,t}}{P_t} L_{goods,t}(i) - r_t^k K_t(i) - \frac{P_{M,t}}{P_t} Int_{goods,t}(i) - \frac{P_{oil,t}}{P_t} Oil_{goods,t}(i) - \frac{\kappa_H}{2}\left(\frac{P_{H,t}(i)/P_{H,t-1}(i)}{\pi_{H,t-1}^{\iota_H}\pi^{1-\iota_H}} - 1\right)^2 \frac{P_{H,t}}{P_t} y_{goods,t} \tag{24}$$

where price stickiness is introduced via quadratic adjustment costs with level parameter κ_H and ι_H captures the extent to which price adjustments are indexed to past inflation in the domestic goods sector. A domestic firm's objective is to choose the quantity of labor, good inputs, capital, oil intensity and the price of its output each period, to maximize the present value of profits subject to the demand function it is facing with respect to its individual output. The first-order conditions of the firm with respect to labor, oil, capital and intermediate good inputs can be combined and linearized to relate capital, labor, oil and intermediate input goods demand.

$$\hat{K}_t = \tau_{goods}\hat{w}_{goods,t} + \hat{L}_{goods,t} - \tau_{goods}\hat{r}_t^k \tag{25}$$

$$\hat{Oil}_{goods,t} = \tau_{goods}\hat{w}_{goods,t} + \hat{L}_{goods,t} - \tau_{goods}\hat{p}_{oil,t} \tag{26}$$

$$\hat{Int}_{goods,t} = \tau_{goods}\hat{w}_{goods,t} + \hat{L}_{goods,t} - \tau_{goods}\hat{p}_{M,t} \tag{27}$$

[3]Utilized capital, K_t, is equal to the capital stock times the utilization rate. $K_t = u_t\bar{K}_{t-1}$

The first-order condition with respect to price yields the linearized New Keynesian Phillips curve for domestic goods prices as:

$$\hat{\pi}_{H,t} - \iota_H \hat{\pi}_{H,t-1} = \beta E_t[\hat{\pi}_{H,t+1} - \iota_H \hat{\pi}_{H,t}] - \frac{\Theta_H - 1}{\kappa_H} \left(\hat{p}_{H,t} - \hat{MC}_{goods,t} \right) + \hat{e}_{H,t} \tag{28}$$

where $p_{H,t}$ is the relative price of home goods, ($p_{H,t} = \frac{P_{H,t}}{P_t}$), and $MC_{goods,t}$ is the marginal cost of home goods production defined as

$$\hat{MC}_{goods,t} = (1 - \alpha_K - \alpha_{O,goods} - \alpha_{M,goods})\hat{w}_{goods,t} + \alpha_K \hat{r}_t^k + \alpha_{O,goods}\hat{p}_{oil,t} + \alpha_{M,goods}\hat{p}_{M,t} - \hat{e}_{a,goods,t} \tag{29}$$

The service and housing sectors operate under the same structure with their own price adjustment costs and sectoral price indexation. The only difference being their respected CES technology production functions. The intermediate services producer's CES production function is:

$$\begin{aligned} y_{serv,t}(i) = e_{a,serv,t} \Bigg[&(1 - \alpha_{O,serv} - \alpha_{M,serv} - \alpha_{M,goods,serv})^{\frac{1}{\tau_{serv}}} L_{serv,t}^{\frac{\tau_{serv}-1}{\tau_{serv}}} + \\ &\alpha_{M,serv}^{\frac{1}{\tau_{serv}}} Int_{serv,t}^{\frac{\tau_{serv}-1}{\tau_{serv}}} + \alpha_{M,goods,serv}^{\frac{1}{\tau_{serv}}} Int_{goods,serv,t}^{\frac{\tau_{serv}-1}{\tau_{serv}}} + \alpha_{O,serv}^{\frac{1}{\tau_{serv}}} Oil_{serv,t}^{\frac{\tau_{serv}-1}{\tau_{serv}}} \Bigg]^{\frac{\tau_{serv}}{\tau_{serv}-1}} \end{aligned} \tag{30}$$

while the intermediate housing producer's CES production function is:

$$y_{hou,t}(i) = e_{a,hou,t} \left[(1 - \alpha_{land})^{\frac{1}{\tau_{hou}}} L_{hou,t}^{\frac{\tau_{hou}-1}{\tau_{hou}}} + \alpha_{land}^{\frac{1}{\tau_{hou}}} Land^{\frac{\tau_{hou}-1}{\tau_{hou}}} \right]^{\frac{\tau_{hou}}{\tau_{hou}-1}} \tag{31}$$

2.3 Global Oil Markets

As in Khalil (2022) a dominant oil producer (DOP) is our third-region of the model. The DOP produces tradable oil and non-tradable services. It imports consumption goods and oil producing imports from the domestic economy and the ROW economy. Oil production of the dominant producer follows the following Cobb-Douglas technology

$$Oil_{supply,dom,t} = e_{a,oil,dom,t} L_{oil,dom,t}^{\alpha_{L,oil,dom}} X_{oil,dom,t}^{\alpha_{x,dom}} \tag{32}$$

where $L_{oil,dom,t}$ and $X_{oil,dom,t}$ are the labor and imported goods needed to produce oil and $e_{a,oil,dom,t}$ is an oil production shock. Further, $\alpha_{L,oil,dom}$ and $\alpha_{x,dom}$ denote the share of labor and imported global goods in total oil production. Oil production is assumed to need imported goods from the domestic economy and the ROW economy to match the positive correlation between goods production and oil prices seen in the data and modeled in Khalil (2022) and Nakov and Nuno (2013). Global Oil markets clear such that

$$Oil_{goods,t}+Oil_{serv,t}+Oil^{*}_{goods,t}+Oil^{*}_{serv,t}+Oil_{inv,t}-Oil_{inv,t-1}=Oil_{supply,dom,t}+Oil_{supply,fringe,t} \tag{33}$$

where oil demand and the change in oil inventories (Oil_{inv}) will equal supply from the dominant oil producer and supply from the fringe producers assumed to be an AR(1) exogenous process as in Kilan and Murphy (2014). The DOP incorporates global oil demand, oil production provided by the fringe, the level of global oil storage when deciding upon oil production while optimizing domestic utility in terms of domestic consumption and labor. More details about the DOP economy can be found in the online Appendix.

2.4 Monetary and Fiscal Policy

The *monetary authority* follows the following linearized Taylor rule to set the short-term nominal interest rate that adjusts due to deviations of inflation, currency value and output from their steady state levels.

$$\hat{R}_t=\rho\hat{R}_{t-1}+(1-\rho)\left[r_\pi\hat{\pi}_t+r_y\hat{y}_t+r_d\hat{d}_t\right]+\hat{\varepsilon}_{r,t}+\sum_{k=1}^{5}\hat{e}^{r}_{k,t-k} \tag{34}$$

where π_t is the inflation rate expressed in deviation away from the central bank's objective of π, y_t is the output gap, $\hat{\varepsilon}^r_t$ is a standard unanticipated monetary policy shock, and $\hat{e}^r_{k,t-k}$ are anticipated monetary policy shocks (forward guidance) known to agents at time $t-k$. In other words, agents may be informed of credible future deviations from the interest-rate feedback rule.

The consolidated government budget constraint is given by

$$g_t + \frac{R_{t-1}}{\pi_t} b_{S,t-1} + \frac{R_{L,t}}{\pi_t} q_{L,t} b_{L,t-1} = \frac{Tax_t}{P_t} + b_{S,t} + q_{L,t} b_{L,t} \tag{35}$$

where g_t denotes real government expenditures, while, $b_{S,t}$ and $b_{L,t}$ represent real short and long-term government bonds held by the general public.

Lump-sum taxes adjust with the level of output and government debt:

$$\frac{Tax_t}{P_t} = \frac{tax}{y} \left(\frac{y_t}{y}\right)^{\tau_y} \left(\frac{b_{S,t-1} + q_{L,t-1} b_{L,t-1}}{b_S + q_L b_L}\right)^{\tau_b} e_{tax,t} \tag{36}$$

where $\frac{tax}{y}$ captures the steady-state level of taxes relative to output, τ_y and τ_b determine the short-run responses of taxes to output and government debt, respectively, and $e_{tax,t}$ is a tax shock (tax transfer from/to households).

Lastly, large-scale asset purchases are modeled through the way in which the monetary and fiscal authorities set the relative supply of short-term and long-term bonds available to the public;

$$\gamma_{b,t} = \frac{q_{L,t} b_{L,t}}{b_{S,t}} \tag{37}$$

where $\gamma_{b,t}$ is exogenous and follows an AR(1) process. A negative shock to $\gamma_{b,t}$ results in a decrease in the supply of long-term government bonds available to the public and an increase in the supply of short-term bonds held by the public. Since the monetary base and short-term bonds are close to perfect substitutes when short-term interest rates are zero or when the central bank pays interest on bank reserves, a negative $\gamma_{b,t}$ shock is equivalent to a large scale asset purchase of long-term bonds by the central bank conducted by increasing the monetary base.

2.5 Market Clearing

The model is completed and connects the economies with the following market clearing equations. Domestic production and imported products are aggregated by final goods producers, who operate in a perfectly-competitive setting. The real domestically-produced final output, y_t, are used in the form of home consumption in goods ($c_{H,t}$), home business investment ($I_{H,t}$), home intermediate input goods ($Int_{H,t}$), home consumption in services ($c_{serv,t}$), intermediate input services ($Int_{serv,t}$), residential investment (HI_t), government purchases in goods and services (g_t) or exported to the ROW or the DOP, resulting in the following resource constraint:

$$y_t = c_{H,t} + I_{H,t} + Int_{H,t} + Int_{serv,t} + c_{serv,t} + HI_t + g_t + y^*_{F,t} + y_{F,dom,t} + a(u_t)\bar{K}_{t-1} \tag{38}$$

where $a(u_t)\bar{K}_{t-1}$ denotes the amount of output affected by capital utilization. Additionally, $y^*_{F,t}$ denotes the foreign region's imports and $y_{F,dom,t}$ the dominant oil producing regions' imports of consumption and oil producing goods; hence, together the domestic regions's exports.

Aggregated consumption, investment and intermediate input goods are made of home and imported consumption ($c_{F,t}$), imported investment ($I_{F,t}$) and imported intermediate input goods ($Int_{F,t}$) which together equal imported final goods in the domestic region ($y_{F,t}$).

$$y_{F,t} = c_{F,t} + I_{F,t} + Int_{F,t} \tag{39}$$

Like assets, final consumption goods, investment goods and intermediate good inputs are constructed as a CES aggregate of their respective home and foreign components respectively. Further, the market clearing conditions for bonds issued by the home economy are given by:

$$b_{S,t} = \frac{B_{H,S,t}}{P_t} + \frac{B^*_{F,S,t}}{P_t} \quad \& \quad q_{L,t}b_{L,t} = \frac{q_{L,t}B_{H,L,t}}{P_t} + \frac{q_{L,t}B^*_{F,L,t}}{P_t} \tag{40}$$

where $B^*_{F,S,t}$ and $B^*_{F,L,t}$ are short and long-term domestic bonds held in the foreign asset portfolio.

The foreign and domestic regions economies are connected through the following balance of payments identity:

$$
\begin{aligned}
&(e_t B_{F,S,t} - e_t R^*_{t-1} B_{F,S,t-1}) + (e_t q^*_{L,t} B_{F,L,t} - e_t R^*_{L,t} q^*_{L,t-1} B_{F,L,t-1}) \\
&\quad - (B^*_{F,S,t} - R_{t-1} B^*_{F,S,t-1}) - (q_{L,t} B^*_{F,L,t} - R_{L,t} q_{L,t-1} B^*_{F,L,t-1}) = P_{H,t} y^*_{F,t} - e_t P^*_{H,t} y_{F,t}
\end{aligned}
\tag{41}
$$

where the right hand side denotes the current account balance for the domestic region, and the left hand side captures the cross-border bond holdings, net of interest payments.

The loan market clearing condition is equal to

$$
Q_t \bar{K}_t = NW_t + ldr_t Dep_t \tag{42}
$$

where the value of capital must be equal to entrepreneurial net worth and the fraction of deposits lent out by the financial intermediary. The model also includes final consumption aggregators, capital producers, entrepreneurs and importers. The details of each along with the log linearized equations of the model can be found in Appendix A1.

2.6 Exogenous Processes

The model is complete with 23 exogenous shocks to each region, three oil shocks and one global trade. There are seven region specific i.i.d. supply shocks to sectoral wages, sectoral domestic price mark-ups, and import price mark-ups, three region specific AR(1) bond demand shocks, four region specific AR(1) demand shocks to business investment, housing, final consumption and goods consumption, four region specific policy shocks to government purchases, taxes, monetary policy rate and an LSAP (bond supply available to the public ratio) shock. Further, two finance AR(1) shocks that are assumed to be correlated across regions, one to net worth and a financial risk shock that directly affects the loan spread.[4] There are also three region specific stationary AR(1) technology shocks to each of the three sectors of the economy. In addition, the domestic region (US) is subject to

[4]The correlated shocks are assumed to be identified in the same way as Alpanda and Aysun (2014) where shocks to the domestic region (US) have a contemporaneous effect on the level of both the domestic and foreign regions's shocks while a financial or productivity shock innovation in the foreign region has a contemporaneous effect on the foreign region, but only a lagged effect on the domestic region's shock levels.

five anticipated monetary policy shocks in the monetary policy interest rate setting rule that are identified off of Federal Funds Rate market expectations as in Del Negro et al. (2013).

3 Estimation

The solved linearized model is both calibrated and estimated using traditional state-space Bayesian estimation techniques as in An and Schorfheide (2007). This section discusses the calibrated parameters and steady states, the data used to estimate the remaining parameters of the model, as well as the prior and posterior results of the estimated parameters for the domestic (US), foreign (ROW) and dominant oil producer (DOP) regions of the model.

3.1 Data

I use 61 quarterly data series for the period 1999Q1 to 2022Q4 as observables in the estimation of the model. The aggregate ROW series are constructed using the weighted average of data from Australia, Canada, China, the Euro Area, Japan and the United Kingdom. The series for the ROW economy are constructed as the weighted average of data series from these countries where each country's relative weight are obtained using the average real GDP of these countries as a share of the ROW total for the sample period, and the same weights were applied for all series and all periods. Financial series from China are not included in the ROW calculation, instead the country weights are rescaled for the remaining five countries.

The observable variables used in the estimation include 25 series that are also used in Gelfer and Gibbs (2023). These include output (y, y^*), government purchases (g, g^*), GDP deflator inflation (π, π^*), imported-goods inflation (π_F, π_F^*), short-term interest rate (R, R^*), long-term interest rate (R_L, R_L^*) as well as the depreciation rate of the US dollar against the ROW currency (d). In addition, eight bond supply observables are used in the estimation. These include short-term bond supply as a percentage of GDP ($\frac{b_S}{y}$, $\frac{b_S^*}{y^*}$), long-term bond supply as a percentage of GDP ($\frac{q_L b_L}{y}$, $\frac{q_L^* b_L^*}{y^*}$) for both the US and the ROW economies, international short-term bond holdings as a percentage of GDP ($\frac{b_{F,S}}{y}$, $\frac{b_{F,S}^*}{y^*}$) and international long-term bond holdings as a percentage of GDP ($\frac{q_L^* b_{F,L}}{y}$, $\frac{q_L b_{F,L}^*}{y^*}$).[5] This data allows for better identified estimates of elasticity of asset substitution parameters and an empirically matched time path for international bond holdings for both the US and ROW inside the model.

For the US, short-term bond supply series were constructed as the sum of the monetary base and government bonds with a maturity of less than one year at issuance. US government short and long-term bond supply series exclude the Federal Reserve holdings of government bonds. For the ROW bond supply data, all outstanding government bonds (minus those held by each country's central bank) are converted into US dollars and the summation from these are used to obtain a measure for the ROW's total short and long-term bond supplies.

There are four financial variables used in the estimation. These include net worth growth (NW, NW^*) and the private sector risk spread (S, S^*). Net worth is calculated using the quarterly growth rate of each country's major stock index and the risk spread is the interest rate difference between BAA bonds and treasuries for the US and BBB (Bloomberg index) bonds and a country's respective treasuries for the remaining five countries of the ROW.

The addition of the three sectors in each economy require an additional 24 sector specific series. These include consumption goods (c_{goods}, c^*_{goods}), consumption services (c_{serv}, c^*_{serv}), business investment (I, I^*) and residential investment (HI, HI^*). Wages in each sector($\pi_{w,goods}$, $\pi_{w,serv}$, $\pi_{w,hou}$, $\pi^*_{w,goods}$, $\pi^*_{w,serv}$, $\pi^*_{w,hou}$), labor in each sector (L_{goods}, L_{serv}, L_{hou}, L^*_{goods}, L^*_{serv}, L^*_{hou})[6], service inflation (π_{serv}, π^*_{serv}) and housing inflation (π_{hou}, π^*_{hou}). Except for the bond supplies, inflation rates, interest rates and the depreciation rate, all data are log-differenced and demeaned prior to estimation.

Further, with the addition of the oil sector in the model, data on crude oil inflation (π_{oil}), supply of OPEC+ oil ($Oil_{supply,dom}$), supply of non-OPEC+ oil ($Oil_{supply,fringe}$) and global oil inventories (Oil_{inv}) are also used in the estimation. As in Khalil (2022) all oil data is from the US Energy Information Administration. For the US, three additional datasets are used to help match the empirical data of aggregate consumption, labor and imports.

[5] The data on bond holdings are only available at year end from the Treasury International Capital (TIC) database, therefore, the known data are connected to Q4 for each year in our sample and all other quarters are linearly extrapolated.

[6] The goods sector uses wages and hours worked in manufacturing and the housing sector uses wages and hours worked in the construction sector.

Finally, given the existence of the ZLB over our sample window and the desire to analyze the monetary policy of forward guidance, I identify the anticipated monetary policy shocks, following Del Negro and Schorfheide (2013) and augment the measurement equations with the following expectations for the US Policy Rate (R_t):

$$\text{Federal Funds Rate}^{Exp}_{t,t+1} = 400R + \Lambda_R G(\theta)^1 S_t \tag{43}$$

$$\vdots \tag{44}$$

$$\text{Federal Funds Rate}^{Exp}_{t,t+5} = 400R + \Lambda_R G(\theta)^5 S_t \tag{45}$$

where Federal Funds Rate$^{Exp}_{t,t+k}$ is the market's time t expectations (OIS data) for the policy rate k quarters ahead. Λ_R is the row of Λ in the observable equation corresponding to the policy rate, $G(\theta)$ is the transitional matrix of the DSGE model and S_t is the state vector of the state-space model. Having these empirical datasets ensures that agents in the model never anticipate a negative policy rate and thus upholds the ZLB in estimation. The data sources, measurement equations, as well as other details regarding the construction of the ROW aggregates, can be found in the online Appendix.

3.2 Calibrated Parameters

I calibrate certain under-identified parameters to values seen in the literature and important steady-state levels and ratios for many variables based on sample data from 1999-2022. The relative size of the ROW economy to the US economy is calibrated to 1.85 based on the average yearly ratio of the six countries' GDP in real US dollars to real GDP for the US over the sample period. The steady state GDP share of government purchases (g/y) is calibrated to the average proportion of government purchases of US GDP and ROW GDP over the sample period. A domestic price mark-up of 1.25 is assigned to every sector, a depreciation rate of capital (τ) of 0.025, and a depreciation rate of housing (τ_h) of 0.01. The capital share of production in the goods sector (α_K), the CES technology of the goods sector (τ_{goods}) and a calibrated steady state risk premium are set to imply a steady state share of business investment to GDP (I/y) of 0.127 for the US and 0.207 for the ROW, which correspond with the average share of business investment of both regions over the sample period. The steady state share of exports to US GDP (y_F^*/y) is calibrated to 0.119 to match the data. These steady state component shares along with the implied steady state share of imports to US GDP (y_F/y) from the balance of trade equation imply a steady state share of consumption to GDP (c/y) of 0.63 for the US and 0.5 for the ROW.

The home-bias parameters (γ_c), (γ_I) and (γ_{int}) are calibrated to 0.837 to match the import share to US GDP found in the data over the sample period, while in the ROW, the corresponding parameters, (γ_c^*), (γ_I^*) and (γ_{int}^*) are set to 0.91 given the relative size of 1.85 of the ROW economy relative to the US. The tax level parameters in the two regions, (tax/y) are set to ensure that each government's budget constraint is satisfied given the bond ratios and interest rates at the steady state.

Steady state inflation (π) for the economy, the goods sector and service sector are calibrated to be equal to 2% on an annual basis, while steady state inflation for housing prices ($\pi_{hou}^{obs}+\pi$) is set at 4%. The nominal short and long-term interest rates (R, R_L) are calibrated to equal 4.1% on annual basis in both regions to correspond with a 2.1% annual real interest rate. The steady state risk spread (S) is set to 2.3% for both regions, just below the sample data for the US and above the sample data for the ROW.

For the individual sectors (c_{serv}/y) and (Δ_{hou}) are set to 0.45 and 0.039 for the US and 0.294 and 0.058 for the ROW to match the data of consumption services and residential investment to GDP respectively. Given (g/y), (g_{goods}) and the two aforementioned parameters, an implied steady state level of service production in each economy (γ_{serv}) is 0.59 for the US and 0.46 for the ROW. The share of intermediate inputs in the goods and service sectors ($\alpha_{M,goods}$), ($\alpha_{M,serv}$), ($\alpha_{M,goods,serv}$) are calibrated to imply similar input factors from 2012 US input-output tables. The share of oil used in each sector's production ($\alpha_{O,goods}$) and ($\alpha_{O,serv}$) are calibrated to imply an oil intensity of around 3% of GDP and match values obtained from 2012 US input-output tables. The steady state share of OPEC+ output in global oil production $\left(\frac{Oil_{s,dom}}{Oil_s}\right)$ is calibrated to 0.52 and the steady state ratio of global oil inventories to global oil supply $\left(\frac{Oil_{inv}}{Oil_s}\right)$ is set to 0.33 based on data from the US Energy Information Administration. A discussion about other calibrated parameters including those involving the portfolio share parameters can be found in the online Appendix A2.

3.3 Prior and Posterior Estimates

The structural parameter marginal priors follow Gelfer and Gibbs (2023), Rees et al. (2016) and Del Negro and Schorfhiede (2013) priors. Tables A2 and A3 report the prior distributions used for each estimated parameter, the corresponding estimates for the posterior mean and the 90% posterior interval.[7]

The estimates for the wage adjustment cost parameters in each sector[8], (κ_j^{est}), indicate very high levels of wage stickiness in both the US and ROW. Turning to prices, I see more price stickiness in the services sector compare to the goods and housing sector both in the US and ROW. This is in line with Bils and Klenow (2004) and Barsky et al. (2007) who both found that goods prices and housing prices are more likely to change than service prices based on firm price changing data. We will see that this is an important estimate of the model that will drive some of the asymmetric effects of policy based upon goods and services relative demand standing.

I also see that modeling the three sectors in the economy significantly lowers habit consumption from 0.85 for both the US and ROW in Gelfer and Gibbs (2023) to 0.44 and 0.25 respectively. This lower habit consumption estimate is in line with micro data estimates of habit consumption, see Havranek et al. (2017).

The estimates for the portfolio elasticities[9] imply that the elasticity of substitution between short and long-term bonds (λ_a and λ_a^*) for both the US and the ROW are around 1.8. The elasticity of substitution between short-term domestic and foreign bonds (λ_S and λ_S^*) are found to be fairly inelastic for both the US and ROW with estimates centered around

[7] I construct the posterior distribution estimates using a standard Metropolis-Hastings algorithm, using a single chain of 1,000,000 draws with a 25% initial burn-in phase. Convergence is then confirmed by the convergence diagnostic test of Geweke (1999).

[8] The auxiliary price adjustment cost parameter is defined as

$$\kappa_j = \frac{(\Theta_j - 1)\kappa_j^{est}}{(1-\kappa_j^{est})(1-\beta\kappa_j^{est})} \tag{46}$$

for $j = \{H, serv, hou, F, w_{goods}, w_{serv}, w_{hou}\}$. This makes the price and wage adjustment cost estimates comparable to the literature which uses Calvo (1983) type price and wage setting.

[9] The auxiliary portfolio elasticity parameters for $j = \{a, S, L\}$ is defined as:

$$\lambda_j = \frac{\lambda_j^{est}}{1-\lambda_j^{est}} \tag{47}$$

0.25 and 0.35 respectively. Finally, the elasticity of substitution between long-term domestic and foreign bonds (λ_L and λ_L^*) show a notable difference between the US and ROW. The US is estimated to have an elasticity of 0.35, while the ROW has an elasticity estimate of 0.72, suggesting that the elasticity of substitution in the international bond portfolio is greatest between long-term ROW bonds and US bonds owned by the ROW.[10]

The posterior estimates for the other structural parameters are in line with estimates in the related DSGE literature. The estimates for λ_c indicates that the elasticity of substitution between domestic and imported consumption goods is around 1.1 in the US and 1 for investment goods λ_I. I find that the estimates of λ_{int} to be much lower and suggests that the elasticity of substitution between domestic and imported intermediate good inputs is around 0.4 The corresponding numbers for goods and services elasticity of substitution (λ_{type}) and sectoral labor supply elasticity of substitution (η_l) are 0.87 and 0.8 in the US, respectively.

4 Model Dynamics

This section discusses the overall dynamics of the model and the impulse response functions (IRFs) for selected shocks that are pointed to as common disturbances of the pandemic and the recovery period. We will see that many of these shocks indeed contribute to the dynamics of both real and nominal variables of this period according to the estimated model, including the shift to goods from services after June 2020, the rise in US imports and import prices and the inflation surges in all prices soon after. We will also see that many of these shocks amplify the macroeconomic effects of large scale asset purchases conducted by a central bank. In particular, we will examine consumer demand shocks, sector specific demand shocks, sector specific supply-side price mark-up shocks, as well as fiscal and monetary policy shocks.

[10] As in Gelfer and Gibbs (2023), the foreign bond holding data series used in the estimation allow the posterior estimates for λ_S are λ_L to significantly leave their prior distributions.

4.1 Model Moments

We can see the importance of including multi-sectors, international trade and international portfolios into the model by examining Table 1. This table documents the second moments of the baseline model and compares them to the second moments of the serviceless model, the no international trade model and the no portfolio model. The baseline model is able to replicate the second moments of output growth, consumption growth, consumption services growth, business investment growth, import growth, inflation, inflation by sector and the real exchange rate as seen in the data. Further, the baseline model is able to capture the empirical correlation values seen in sectoral consumption growth and sectoral inflation.

Table 1: Simulated Second Moments of the Models

	Data	Baseline	No Services	No Int'l Trade	No Int'l Portfolio
std($Y_t - Y_{t-4}$)	2.08	2.24	2.21	2.38	2.2
std($C_t - C_{t-4}$)	2.35	2.18	2.66	2.03	2.18
std($C_{goods,t} - C_{goods,t-4}$)	3.23	2.35	2.66	1.98	2.10
std($C_{serv,t} - C_{serv,t-4}$)	2.56	2.52	-	2.55	2.48
std($Y_{F,t} - Y_{F,t-4}$)	7.05	5.33	3.92	-	3.90
std($I_t - I_{t-4}$)	5.99	7.31	4.3	6.50	6.32
std($\sum_{i=t}^{t+3} \pi_i$)	1.29	1.29	1.78	1.56	1.35
std($\sum_{i=t}^{t+3} \pi_{goods,i}$)	2.46	2.80	1.85	3.27	2.86
std($\sum_{i=t}^{t+3} \pi_{serv,i}$)	0.98	0.96	-	1.16	1.02
std($rer_t - rer_{t-4}$)	5.16	4.62	4.80	-	3.29
Corr(C_{goods}, C_{serv})	0.35	0.43	-	0.22	0.40
Corr(π, π_{goods})	0.80	0.64	0.99	0.67	0.67
Corr(π, π_{serv})	0.85	0.89	-	0.89	0.89
Corr(π_{goods}, π_{serv})	0.60	0.33	-	0.28	0.25

When the service sector is shut down (No services) the standard deviation falls well below those seen in the data for import and business investment growth. The standard deviation of inflation increases significantly and of course the correlation of services and goods dynamics seen in the data disappears. When there is no international trade in the model inflation is much more volatile than is seen in the data and the correlation between goods and services consumption falls below its empirical observation. When the international portfolio is not modeled the second moments of import growth and the real exchange rate fall significantly below the second observed moments of the data. In all, a multi-sector, open-economy model with modeled international unconventional monetary policy is needed to replicate the moments seen in the data for sectoral consumption, sectoral inflation and international trade and allows us to do the rich investigations that follow.

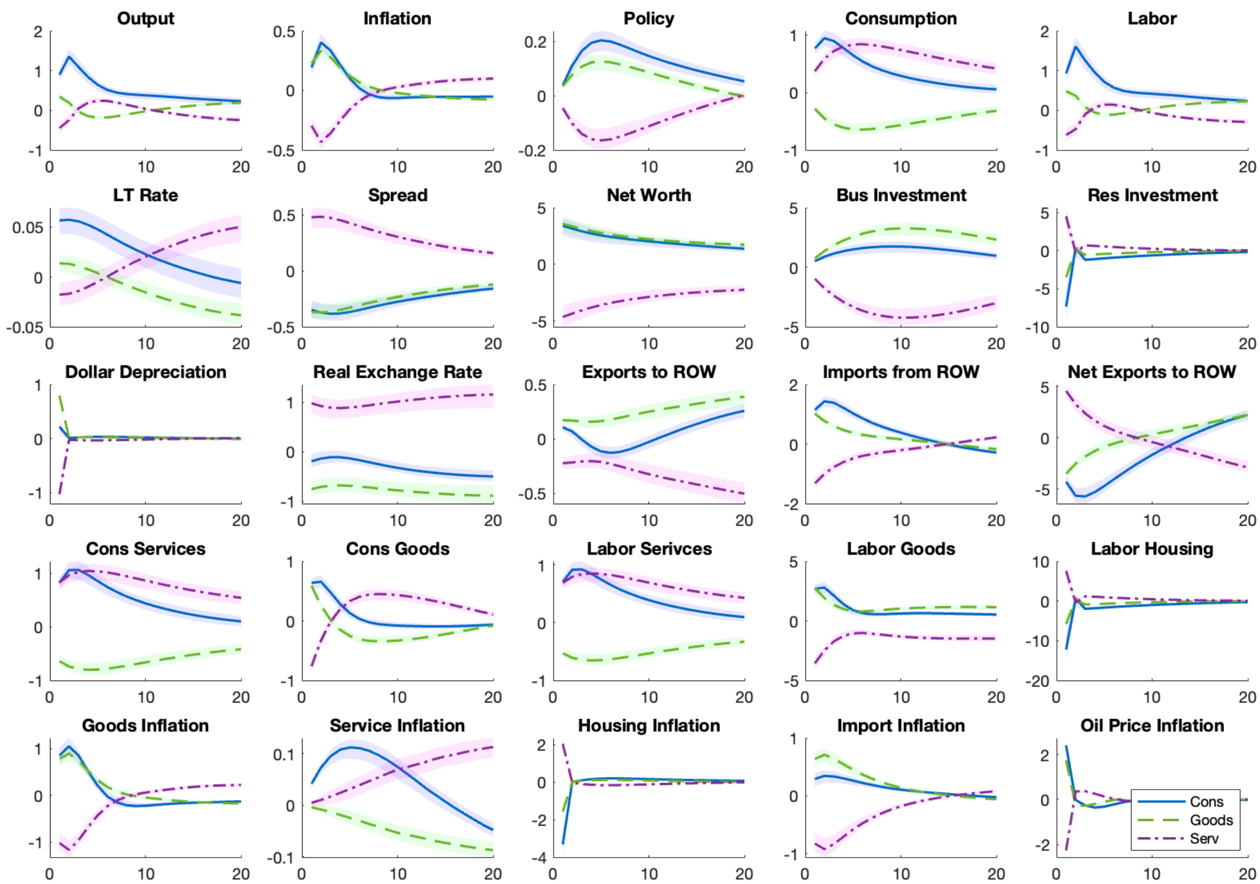
4.2 Sector Supply and Demand Shocks

Consumer Demand Shocks–Figure 2 displays the IRFs of three kinds of consumer demand shocks. The solid blue line plots a positive aggregate consumption preference shock while the dashed green line plots a goods consumption demand shock and the dashed purple line plots a service consumption demand shock. The latter two are scaled to match the effects of the aggregate consumption shock in their respective consumption sector.

When examining the sector-specific consumption demand shocks, we observe that each shock generates demand-pull effects within its own sector, raising output and prices, but simultaneously induces negative spillovers in the opposite sector, reducing both output and prices there. These asymmetric responses stem from differences in structural parameters, such as price stickiness, labor intensity, and input-output linkages across the goods and services sectors.

A positive goods consumption shock is initially inflationary due to increased demand in the goods sector. However, after approximately two quarters, the shock becomes mildly contractionary at the aggregate level. This is driven by a decline in overall consumption and a reduction in hours worked in the services sector, which offsets the initial expansion. In contrast, a positive services consumption shock leads to a deflationary aggregate response. The fall in goods sector prices outweighs the rise in service sector prices, resulting in a net decline in inflation. Over time, this shock stimulates aggregate consumption, output, and labor, as lower prices in the goods sector improve real purchasing power and shift resources toward the expanding services sector. Additionally, the relative decline in goods demand under a services shock reduces demand for imports, business investment, and oil, reflecting the goods sector's stronger ties to tradeables and capital-intensive production.

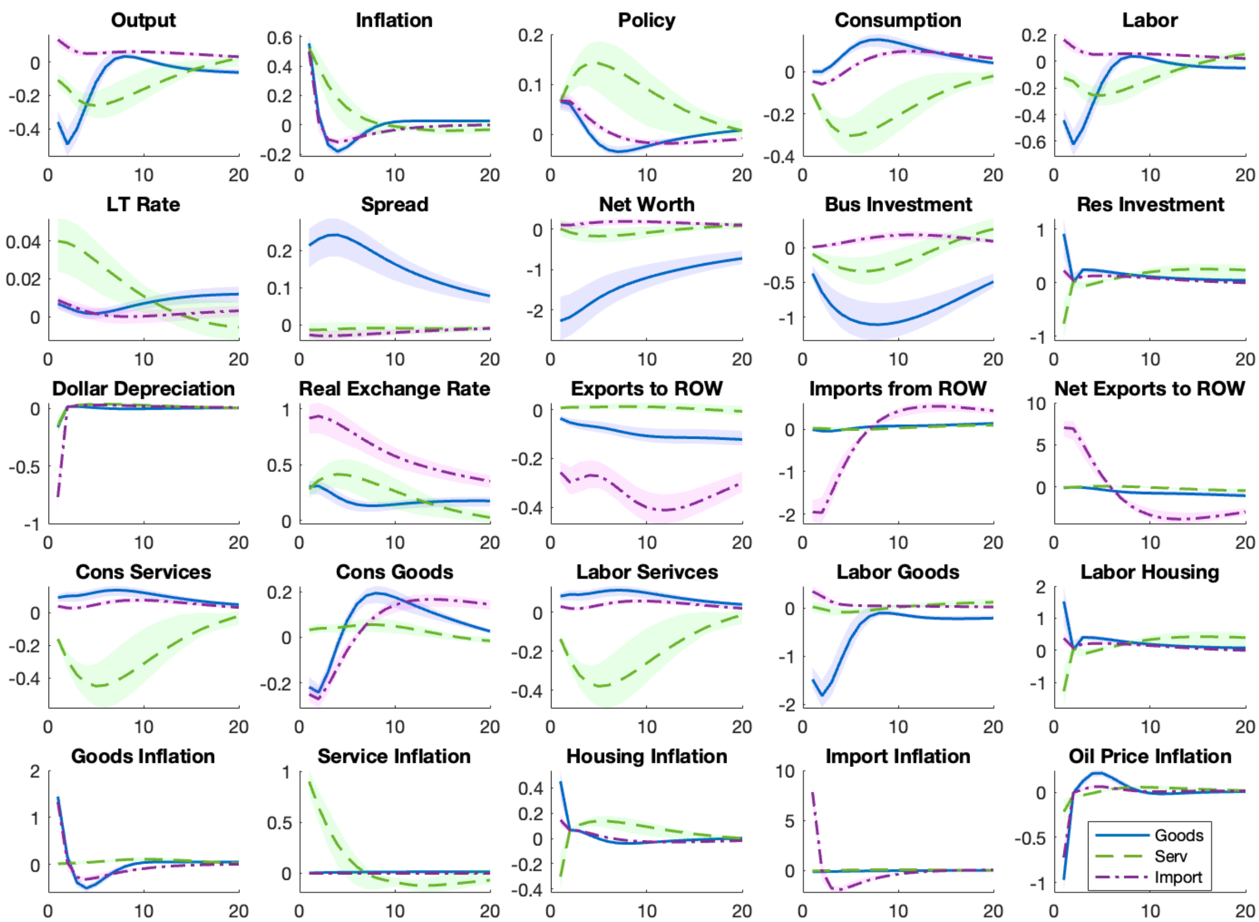
Figure 2: Consumption Demand Shocks



Notes: The solid blue line plots a positive aggregate consumption shock while the dashed green line plots a positive goods consumption shock and the dashed purple line plots a positive service consumption shock. The consumption shock size corresponds to a one estimated standard deviation, while the sector specific shock sizes are calibrated to correspond to the same impact of the consumption shock in their respective sectors. All responses plot the % deviation away from each variable's respected steady state value on the y-axis. All interest rates and inflation rates are annualized.

Supply-side price mark-up shocks–Figure 3 plots the effects of positive price mark-up shocks in the goods, services and import sectors. Among these, the services sector shock generates the most persistent increase in aggregate inflation, lasting approximately eight quarters. The inflationary effects of the goods and import price mark-up shocks reside more quickly, typically within three to four quarters.

Figure 3: Price Mark-Up Shocks



Notes: The solid blue line plots a positive price mark-up shock in the goods sector, while the dashed green line plots a positive price mark-up shock in the service sector and the dashed purple line plots a positive price mark-up shock to imports. The price mark-up shock to services size corresponds to a one estimated standard deviation, while the other two shock sizes are calibrated to match the overall effect of aggregate inflation of the service price mark-up shock. All responses plot the % deviation away from each variable's respected steady state value on the y-axis. All interest rates and inflation rates are annualized.

The import price mark-up shock produces dynamics similar to a domestic goods price mark-up shock, raising goods inflation and contributing to overall inflation. However, unlike the domestic shock, the import shock is mildly expansionary for aggregate output and labor. This occurs because the rise in import prices leads to a decline in imports, which in turn stimulates domestic goods production. The substitution away from foreign goods and intermediate inputs boosts domestic demand, increasing labor and output in the goods-producing sector.

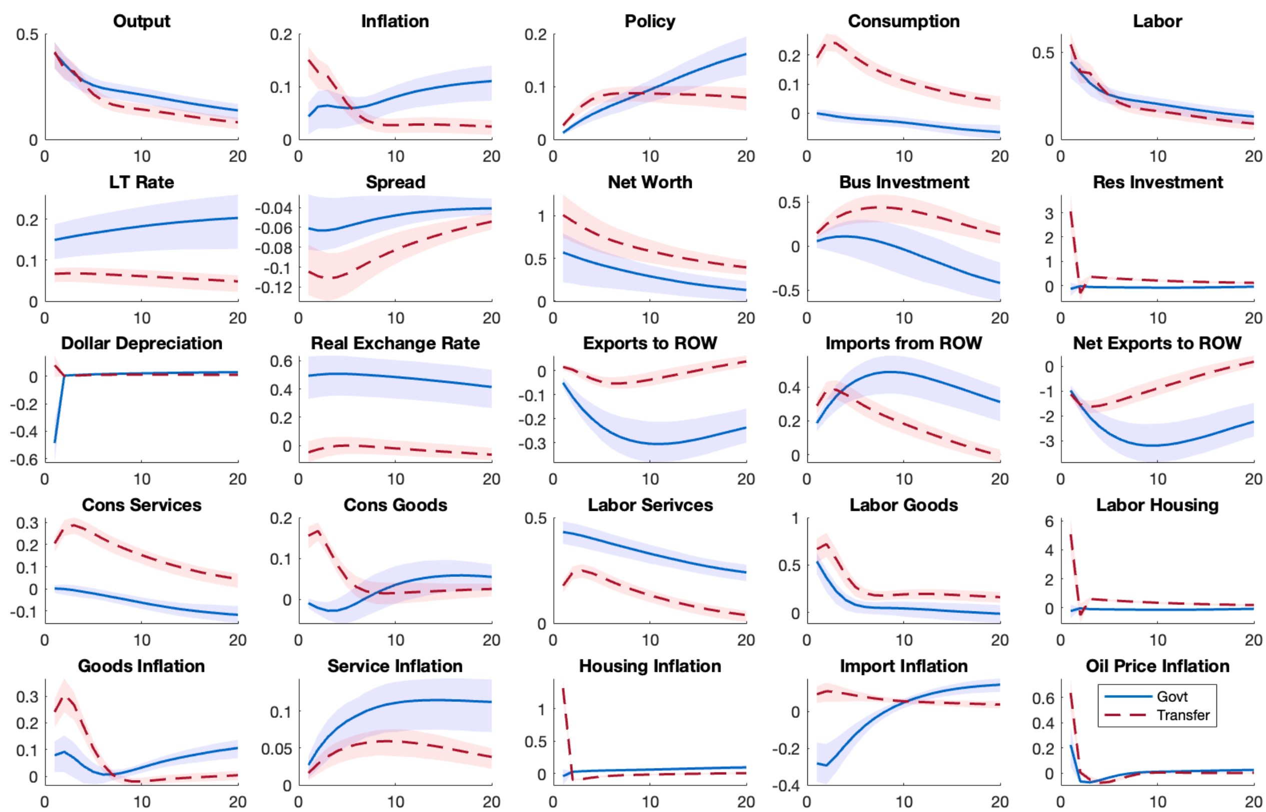
4.3 Fiscal and Monetary Policy Shocks

An important part of the response to the COVID pandemic and its aftermath has been through the use of different methods of fiscal and monetary policy. Unlike traditional New Keynesian DSGE models who model fiscal and monetary policy in terms of government purchases and changes in the policy rate, the model of this paper has those traditional shocks as well as an avenue to model government transfer (e_{tax}) shocks, large-scale asset purchase (γ_b) shocks and forward guidance shocks (e^r_{t-k}). In this subsection we look at the dynamics associated with each one, first the fiscal policy shocks and then the monetary policy shocks.

Fiscal Policy–Figure 4 plots two kinds of fiscal policy, the solid blue line presents the dynamics from a direct increase in aggregate demand in the form of direct government purchases, while the dashed red line presents the dynamics resulting from a direct transfer payment (negative tax shock) from the government budget to the household. Both increase output and inflation but in very different ways.

The transfer payment stimulates household consumption (mostly consumption services) and residential investment, leading to a stronger effect in prices in all sectors and hours worked. This is counter to the direct government purchase which stimulates output and inflation to a lesser but more persistent way while eventually crowding at business investment and exports over time. This is due to the fact that both short-term and long-term rates remain above steady state for a significant period of time after the direct purchase when compared to the direct household transfer. We will see that the magnitude and frequency of these two polices were very different between 2008-2010 vs 2020-2022 and thus the contribution of fiscal policy towards GDP and inflation is very different between the two time periods.

Figure 4: Fiscal Policy Shocks



Notes: The solid blue line plots a positive Government purchase shock while the dashed red line plots a negative tax shock (transfer) to the household. All shocks corresponds to a one estimated standard deviation. All responses plot the % deviation away from each variable's respected steady state value on the y-axis. All interest rates and inflation rates are annualized.

Monetary Policy–The comparison of the types of monetary policy is depicted in Figure 5, which plots impulse responses of different macroeconomic variables to three monetary policy shocks. The dashed red lines depict the IRF of a conventional policy shock to the Taylor rule. The size of the shock is calibrated to lower the policy rate by 25 basis points. Output, hours worked, consumption of both types, investment of both types and inflation all increase on impact. The open-economy variables respond as they should with the US dollar depreciating and net exports increasing. One observation of note is that goods consumption actually falls after 3 quarters as the relative higher price of goods and the increase demand in business investment crowds out household goods consumption.

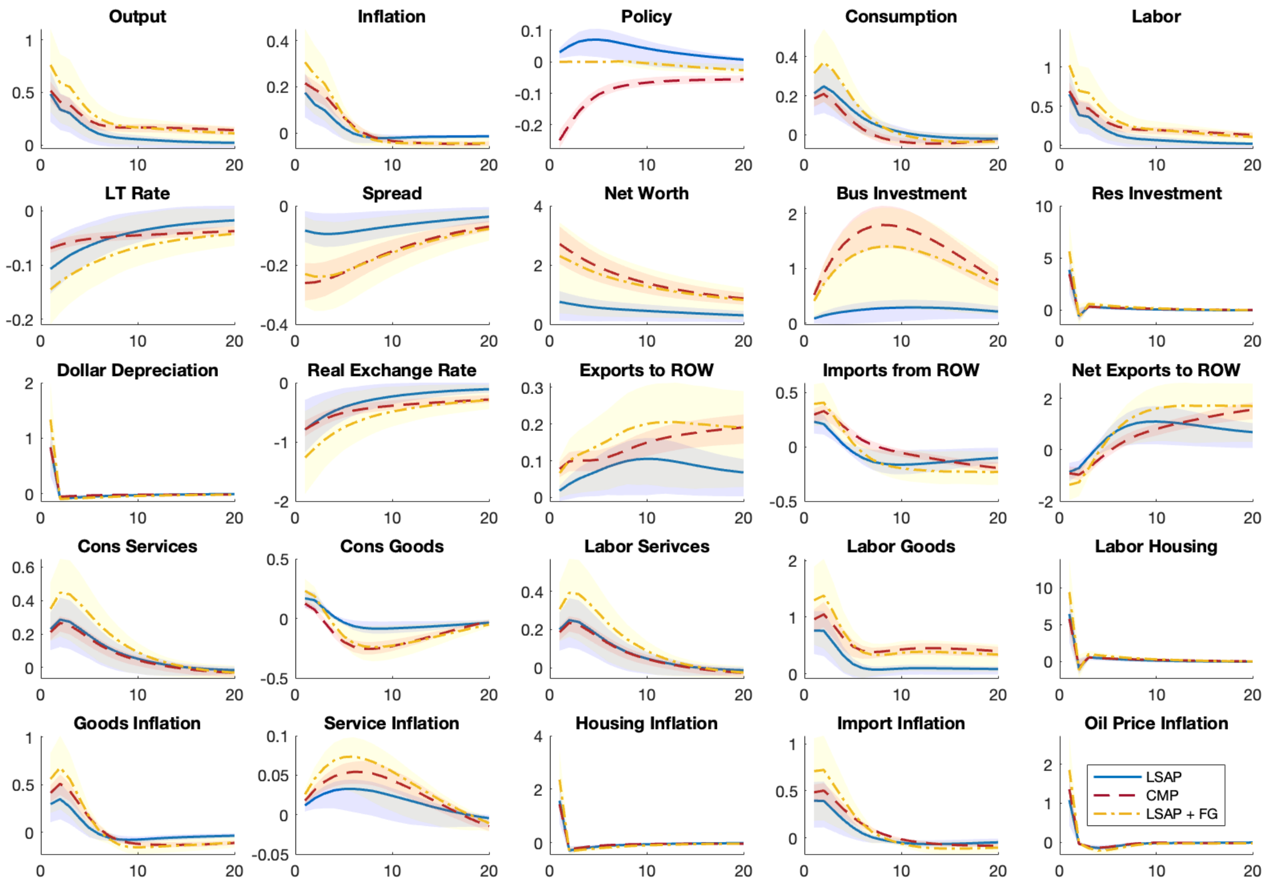
Responses to an LSAP shock are depicted by the solid blue line. This policy intervention is scaled for an LSAP shock that is equivalent to a long-term asset purchase of 1.5% of steady state annual GDP by the central bank at impact. The purchase is initially conducted at the model's steady state. We see that the LSAP shock has a positive impact on output, hours, consumption of both types, residential investment and inflation on impact. As a result the policy rate increases after the LSAP shock. Business investment is marginally affected after the LSAP shock and goods prices rise by a smaller amount creating an increase in household goods consumption.

Comparing to other LSAP empirical results seen in the literature, the long-term interest rate declines by about 15 basis points after the shock in line with the estimated impact on U.S. long-term yields in the empirical literature (Hamilton and Wu (2012), Chen et al. (2012) and Sims and Wu (2021)). The results also correspond with the notion that unconventional monetary policy can have significant effects on foreign exchange rates (see Rogers et al. (2018) and Inoue and Rossi (2019)). Further, we can see that LSAP and CMP policies exhibit close policy substitutes as outlined in Sims and Wu (2021). I find a similar LSAP effect on output as calculated in Boehl et al. (2024), however, I do find significant inflation after the LSAP unlike Boehl et al. (2024) who find significant disinflation. However, much of the inflation impact that is occurring is transmitting through import inflation as a result of the weaker domestic currency and not domestic demand for consumption goods and services suggesting that an open-economy model helps explain additional inflationary pressures of LSAPs.

The last policy we compare is the same LSAP shock described above with a credible commitment by the central bank to not raise the policy rate for four quarters after the LSAP policy intervention. In the model this is simulated by impacting the model with the LSAP shock and then searching for the appropriate anticipated monetary policy shocks that ensure that the policy rate remains unchanged for the next four quarters. This can be also thought of as an LSAP shock that occurs during a period in which the economy is at the ZLB and is most analogous to unconventional shocks that were seen during the GFC and the initial quarters of 2020.

This policy (LSAP + FG) is depicted by the dotted yellow line. The policy commitment significantly increases the efficiency of LSAP, raising the positive response of output, inflation, consumption of both types and residential investment above regular LSAP and CMP shocks. The policy rate commitment ensures that business investment responds positively

Figure 5: Monetary Policy Shocks



Notes: The solid blue line plots an LSAP shock equivalent to a long-term asset purchase of 1.5% of steady state GDP by the central bank. The dashed red line plots the response of a shock equivalent to a 25 basis point fall in the policy rate. The dotted yellow line plots the response of an LSAP shock equivalent to a long-term asset purchase of 1.5% of steady state GDP by the central bank with a year's long commitment of keeping the policy rate unchanged (LSAP with Forward Guidance (FG)). All responses plot the % deviation away from each variable's respected steady state value on the y-axis. All interest rate and inflation rates are annualized.

but is still below the positive investment impact from a CMP shock. This is because capital prices and net worth increase by a smaller amount compared to a CMP shock. The LSAP with policy commitment further depreciates the domestic currency, resulting in a bigger impact on net exports compared to the other two policy interventions.

5 LSAP Interaction with other Shocks

In this section, I examine how the macroeconomic effects of large-scale asset purchases accompanied by a commitment to stabilize the policy rate, vary depending on the presence of additional concurrent shocks. Drawing on the various shocks discussed in Section 4.2, I demonstrate that the impact of LSAPs on the broader economy and financial markets is highly sensitive to the nature of these accompanying disturbances, whether they involve increased demand in a specific sector, sector-specific price mark-up shocks or complementary fiscal transfers to households.

By analyzing these interaction effects, we gain insight into why unconventional monetary policy had markedly different outcomes following the 2008 financial crisis compared to similar interventions in 2020. To explore these dynamics, I compare impulse response functions from a baseline scenario involving a standalone LSAP and a four-quarter policy rate stabilization commitment, with IRFs from scenarios where the same LSAP and commitment are implemented alongside a concurrent shock. The effect of the policy intervention is isolated by subtracting the IRFs of the concurrent shock. In the following plots, the space between the solid blue lines (LSAP+) and the dashed red lines (LSAP) illustrates how the additional shock modifies the impact of LSAPs on macroeconomic and financial variables. If the two lines overlap, we can infer that the concurrent shock does not interact with the LSAP. Accordingly, we are comparing the following dynamics:

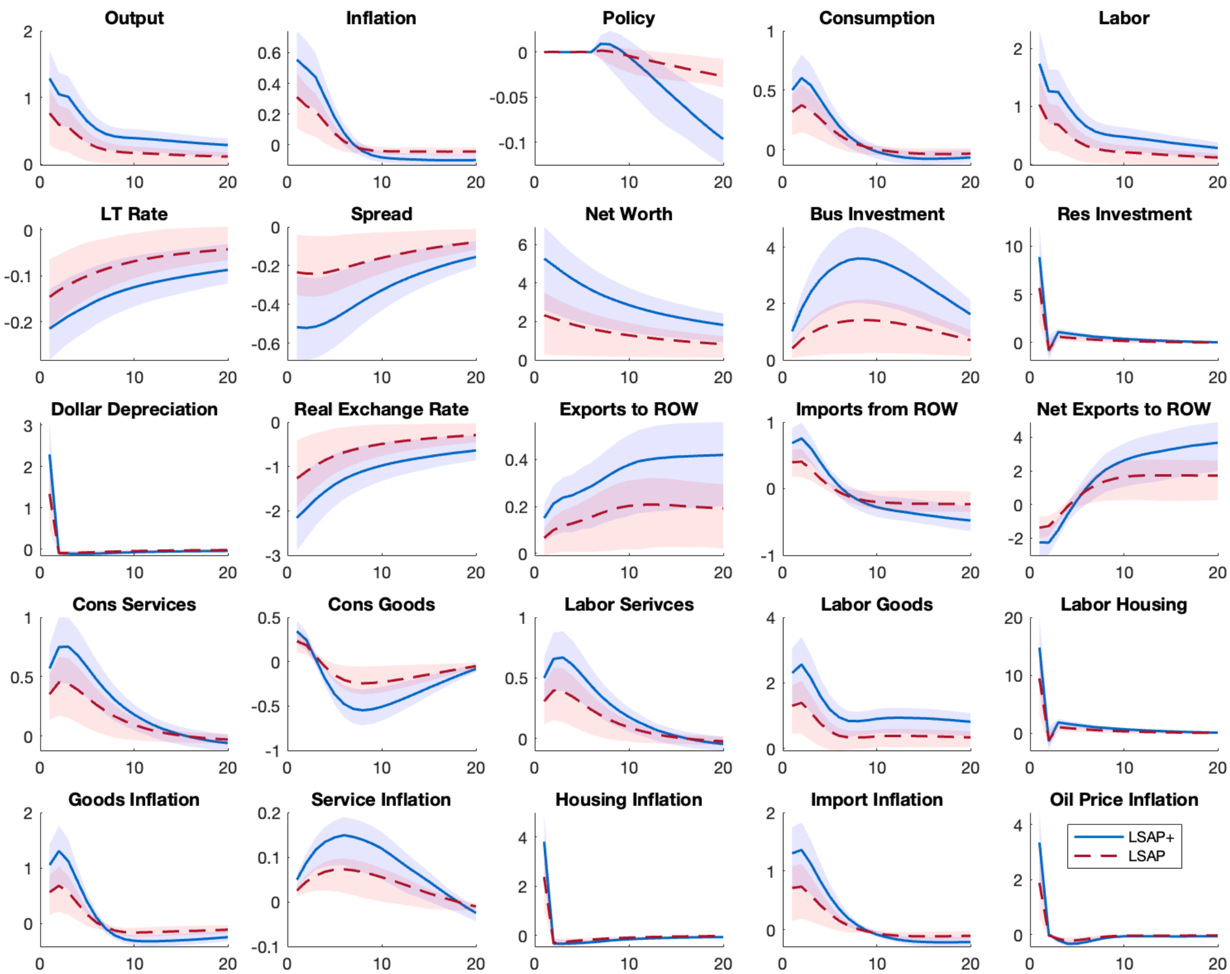
$$\text{IRF(LSAP with policy stabilization commitment and shock of interest)} - \text{IRF(shock of interest)}$$

$$\text{vs}$$

$$\text{IRF(LSAP with policy stabilization commitment)}$$

Figures 6 and 7 show the dynamics of an LSAP purchase when there is concurrent extra consumer demand in the goods sector and service sector respectively. Unconventional monetary policy stimulates output, all types of inflation, hours worked in all three sectors, both types of investment and financial markets more when there is extra demand in the goods sector. This is somewhat due to the fact that extra demand in the more price flexible goods sector raises overall inflation more, causing a stronger positive commitment (anticipated shock effect) by the central bank to maintain its stable policy rate commitment. However, this is not the entire story because even when the Calvo pricing parameters in the goods and services sector are set equal to each other the results of Figure 6 still hold. I will examine this more closely in the next subsection.

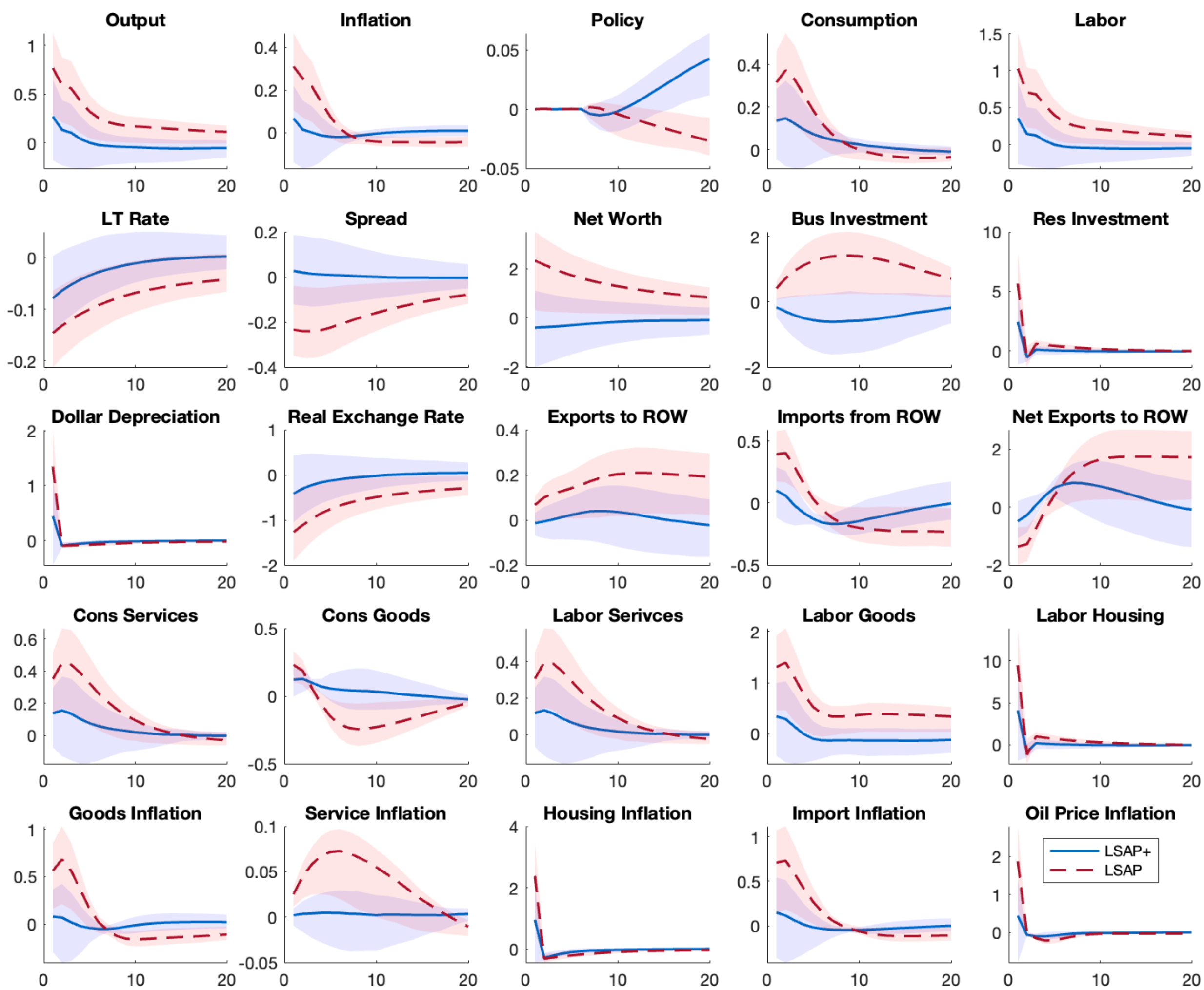
Figure 6: Unconventional Monetary Policy with a Goods Demand Shock



Notes: The dashed red line plots the response of an LSAP shock equivalent to a long-term asset purchase of 1.5% of steady state GDP by the central bank with a year's long commitment of keeping the policy rate unchanged. The solid blue line plots the impact of that same LSAP purchase and commitment with a concurrent shock to goods consumption demand after the dynamics of a stand-alone goods consumption demand shock are subtracted away. All responses plot the % deviation away from each variable's respected steady state value on the y-axis. All interest rate and inflation rates are annualized.

Figures 7 tells a different story when there is excess demand in the services sector. Unconventional monetary policy is less effective in stimulating the economy when there is an equivalent positive demand shock in the services sector. Although expansionary unconventional monetary policy still remains stimulative the increases in almost all the macroeconomic variables is dampened. The high demand in services actually causes a decrease in good prices and quantities as well as imports prices and quantities, thus creating a disinflationary environment for the economy and dampening the positive impact of the policy stabilization commitment. The marginal impact on the goods sector doesn't allow LSAP purchases to significantly increase business investment, capital prices or net worth.

Figure 7: Unconventional Monetary Policy with a Services Demand Shock

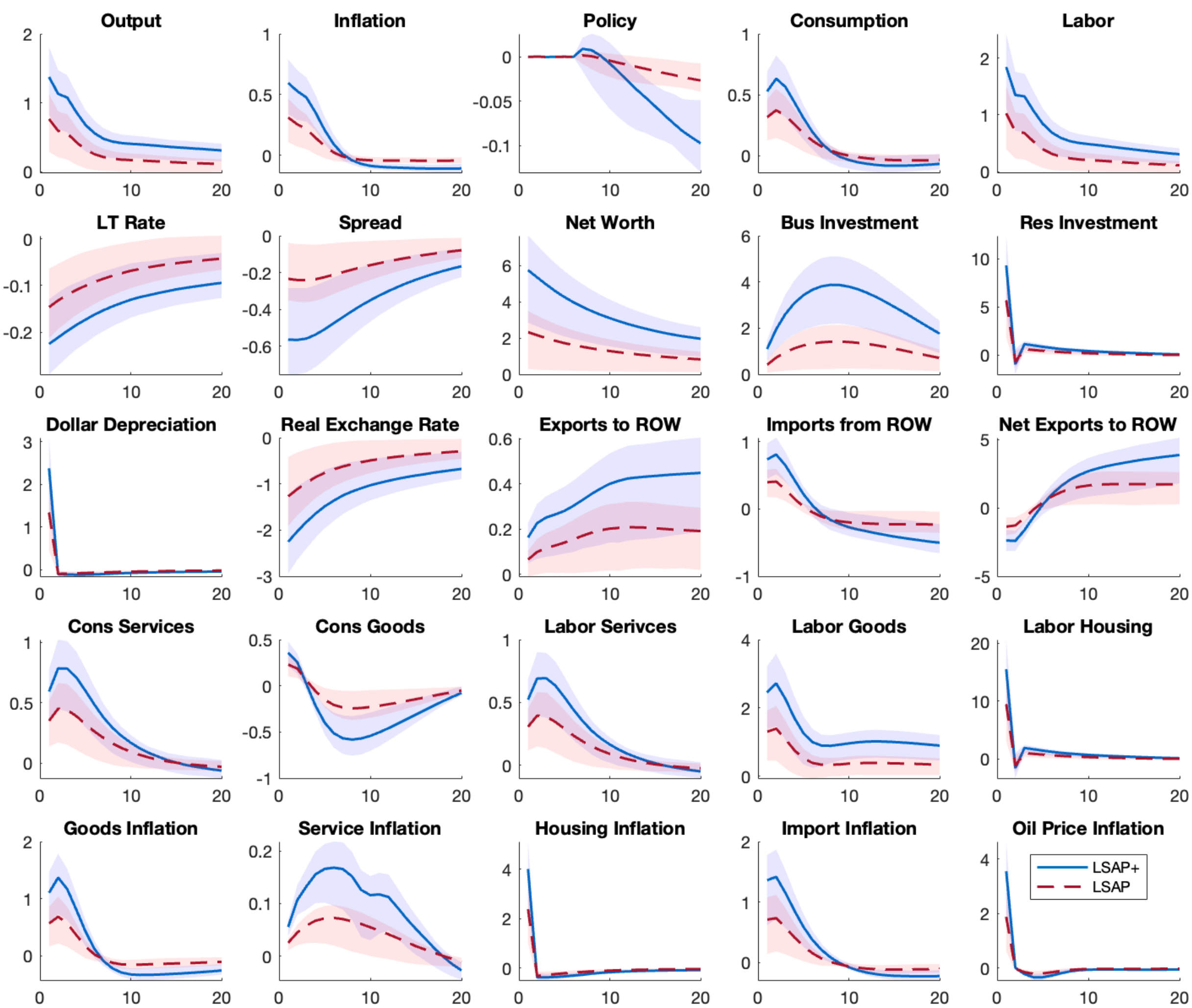


Notes: The dashed red line plots the response of an LSAP shock equivalent to a long-term asset purchase of 1.5% of steady state GDP by the central bank with a year's long commitment of keeping the policy rate unchanged. The solid blue line plots the impact of that same LSAP purchase and commitment with a concurrent shock to services consumption demand after the dynamics of a stand-alone services consumption demand shock are subtracted away. All responses plot the % deviation away from each variable's respected steady state value on the y-axis. All interest rate and inflation rates are annualized.

If instead total demand for aggregate consumption is high (positive aggregate consumption shock) then expansionary unconventional monetary policy becomes even more stimulative compared to just one sector seeing excess demand as can be seen in Figure A18. The combination of both sectors seeing higher demand has a stronger impact on all types of inflation and output, creating a need for a stronger expansionary monetary policy response to stabilize the policy rate. We can see that the effects and efficacy of unconventional monetary policy will vary depending on relative prefrences between household consumption and savings and relative demands between the goods and services sectors.

When comparing supply shocks (positive price mark-up shocks) in the sectors we see that unconventional monetary policy is boosted in an environment when there is a positive price mark-up shock in the services sector and slightly dampened when there is a positive price mark-up shock in the goods sector. Figures 8 and A19 show the interactive dynamics of each.

Figure 8: Unconventional Monetary Policy with a Services Supply Price Mark-up Shock



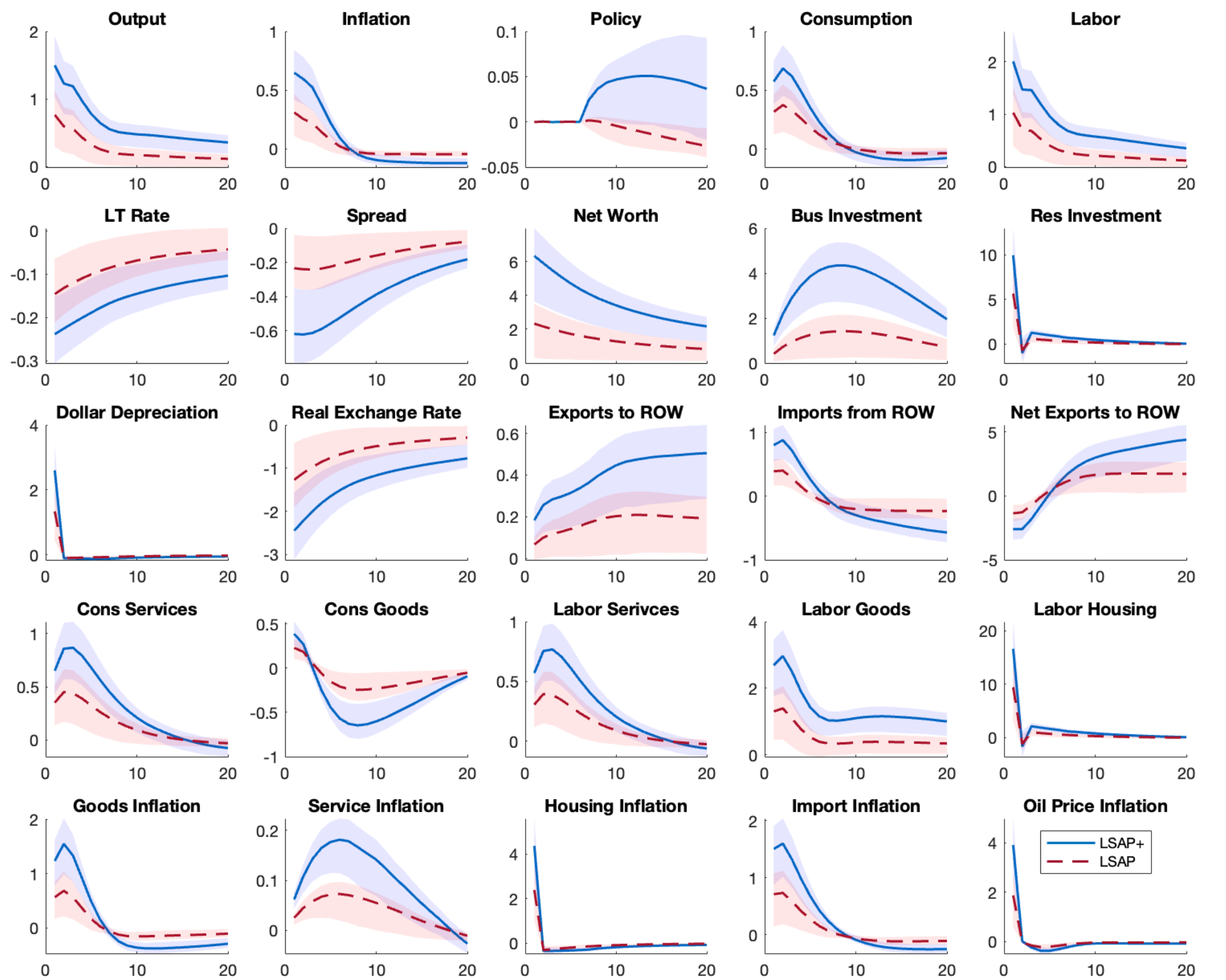
Notes: The dashed red line plots the response of an LSAP shock equivalent to a long-term asset purchase of 1.5% of steady state GDP by the central bank with a year's long commitment of keeping the policy rate unchanged. The solid blue line plots the impact of that same LSAP purchase and commitment with a concurrent shock to services prices after the dynamics of a stand-alone services price mark-up shock are subtracted away. All responses plot the % deviation away from each variable's respected steady state value on the y-axis. All interest rate and inflation rates are annualized.

After the price mark-up shock in the services sector, consumption falls and inflation is more persistent because prices are stickier in the services sector. These conditions allow for LSAPs to be more stimulatory as it creates a stronger and more persistent decline in the real interest rate, stimulating business and residential investment more and in return increasing goods and housing inflation by more. When we compare this to a positive goods price mark-up shock in Figure A19, inflation increases and the real interest rate decreases but only for a few quarters, thus unconventional monetary policy has a lesser effect on business and residential investment demand.

The next interaction effects we will look at in the main body of the text[11] is how unconventional monetary policy interacts with transfer payments in the form of lower taxes on the household. These tax transfers help stimulate the services, goods and housing sectors, creating higher inflation in all three sectors. The policy commitment needed to maintain the policy rate is now stronger creating a further boost to prices and quantities in all three sectors. The interaction effects of transfer payments and LSAP can be seen in Figure 9.

[11] In the appendix, Figure A20 also displays that a concurrent positive net worth shock (asset inflation) boosts the impact of expansionary unconventional monetary policy.

Figure 9: Unconventional Monetary Policy with a Transfer Payments



Notes: The dashed red line plots the response of an LSAP shock equivalent to a long-term asset purchase of 1.5% of steady state GDP by the central bank with a year's long commitment of keeping the policy rate unchanged. The solid blue line plots the impact of that same LSAP purchase and commitment with a concurrent negative shock to taxes (transfer payment) after the dynamics of a stand-alone negative shock to taxes are subtracted away. All responses plot the % deviation away from each variable's respected steady state value on the y-axis. All interest rate and inflation rates are annualized.

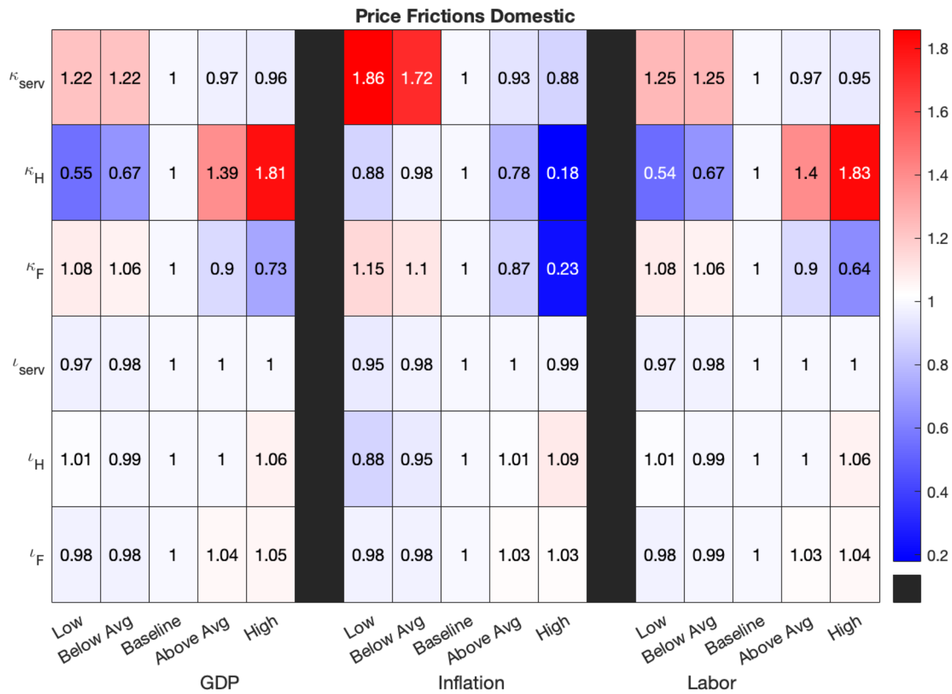
5.1 What Drives Stronger and Weaker LSAP Interaction Effects

The following heat maps illustrate the additional macroeconomic effects of LSAP+ (a large-scale asset purchase combined with high relative goods demand compared to a baseline LSAP scenario where relative goods demand remains neutral. The charts display the incremental impact on GDP growth, inflation, and hours worked over the first year of the policy intervention, across a range of different structural parameter values.[12] All effects are normalized to 1 at the posterior median, allowing for a clear comparison of how different frictions and elasticities shape the effectiveness of LSAP+. When estimating the LSAP+ interaction effect at the median parameter values, LSAP+ leads to a 0.4% increase in GDP growth, a 0.85% rise in inflation, and a 0.48% boost in hours worked relative to LSAP when relative goods demand remains neutral. This subsection aims to unpack the drivers behind the stronger interaction effects observed in Figure 6 of the previous subsection. By mapping the sensitivity of outcomes to variations in price frictions, CES elasticities, firm production structures and financial frictions, these heat maps provide insight into which structural features most influence the extra transmission of unconventional monetary policy that takes place when goods demand is relatively higher than service demand.

Figure 10 reveals how LSAPs interact with a concurrent relative goods demand shocks across different levels of domestic price frictions for GDP growth, inflation, and labor growth over the first year of the LSAP. The parameters κ_{serv}, κ_H and κ_F represent frictions in service prices, goods prices and import prices respectively. The results show that LSAPs have the strongest amplifying effect when combined with high goods price frictions (κ_H) where the normalized extra impact on GDP growth reaches 1.81. This suggests that when domestic goods prices are sticky, LSAPs under relatively high goods demand are more potent in stimulating output. In contrast, import price frictions (κ_F) show a declining interaction effect as they rise, indicating that LSAPs under high goods demand are relatively less effective when import prices are rigid. Service price frictions (κ_{serv}) exhibit the opposite effect as LSAP interaction is greater when service pricing frictions are low. Inflation responses are more pronounced, with the inflation effects all becoming smaller as the pricing frictions increase. Inflation indexation does not seem to play a large role in amplifying the LSAP effects, as the ι parameters show minimal variation across conditions. Overall, the analysis highlights that LSAPs interact most strongly with domestic goods price frictions, underscoring the importance of sector-specific rigidity in shaping the effectiveness of unconventional monetary policy and uncovering its role in the post-COVID inflation surge.

[12] Corresponding parameter values for Low, Below Avg., Baseline, Above Avg. and High can be found in Table A4.

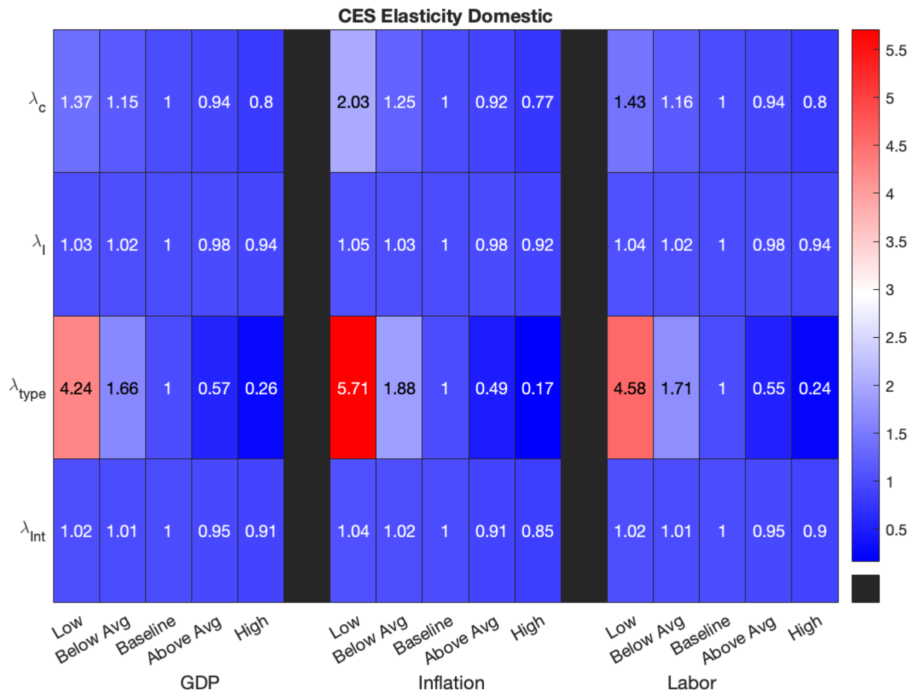
Figure 10: Domestic Price Frictions and LSAP Effect with Relative High Goods Demand



Notes: The heat map shows the additional normalized effects of LSAP+ when relative goods demand is high compared to LSAP when goods demand is neutral at different structural parameter values that model domestic price frictions. The chart compares the extra GDP growth, Inflation, and Hours Growth over the first year of the policy. The values are normalized to one at the posterior median parameter values.

The CES Elasticity heat map of Figure 11 highlights how different substitution elasticities influence the interaction effects of LSAP+. The results show that lower substitution elasticities in consumption types and domestic versus foreign consumption (λ_{type} and λ_c) significantly amplify the impact of LSAP+. For example, a low λ_{type} makes the interaction effect of inflation and GDP growth to be 5 and 4 times higher when compared to the baseline estimate. This indicates that when households face greater difficulty substituting between sectors, the LSAP+ under a relative goods demand shock has a stronger macroeconomic impact. In contrast, when substitution elasticity is high, the interaction effect nearly disappears, as households can easily reallocate spending toward sectors with lower relative prices and demand, dampening the transmission of LSAP+. Meanwhile, intermediate trade elasticity (λ_{Int}) and investment trade elasticity (λ_I) show minimal variation across values, suggesting that these channels play a limited role in shaping the overall interaction effects. This analysis underscores the importance of consumption rigidity in determining the effectiveness of unconventional monetary policy under sectoral demand imbalances.

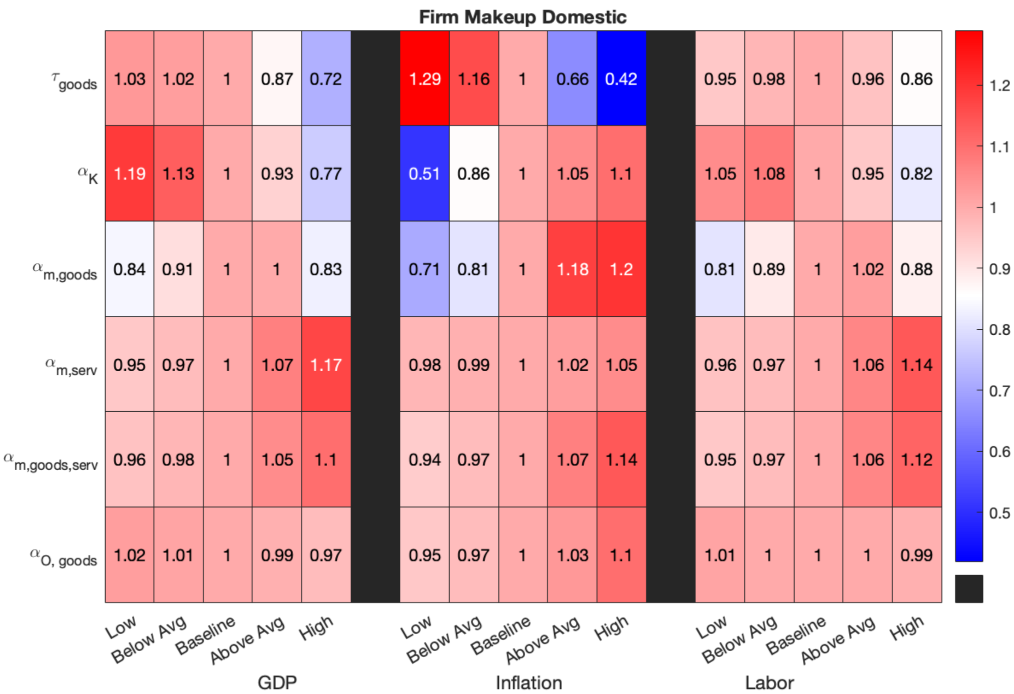
Figure 11: CES Elasticity Parameters and LSAP Effect with Relative High Goods Demand



Notes: The heat map shows the additional normalized effects of LSAP+ when relative goods demand is high compared to LSAP when goods demand is neutral at different structural parameter values that model CES elasticity levels. The chart compares the extra GDP growth, Inflation, and Hours Growth over the first year of the policy. The values are normalized to one at the posterior median parameter values.

The firm input share heat map in Figure 12 explores how the structural composition of production influences the interaction effects of LSAP+ with extra demand in the goods sector. The chart reveals that as intermediate goods become a larger share of production, particularly through higher values of $\alpha_{m,goods}$ and $\alpha_{m,goods,serv}$ the amplification effect of LSAP+ becomes more pronounced. This suggests that economies more reliant on intermediate inputs are more sensitive to sectoral demand shocks and thus more affected by any policy conducted when they are present. Conversely, as the elasticity of substitution in goods production (τ_{goods}) increases, the interaction effect diminishes, indicating that when firms can easily substitute between inputs, the macroeconomic impact of LSAP+ is muted and relative sectoral demand is less important. The capital share in goods production (α_K) also plays a key role, a lower capital share correspond to stronger real effects on GDP and labor, while higher capital share shifts the impact toward higher inflation. Interestingly, oil input into goods production ($\alpha_{O,goods}$) appears to have minimal influence on the interaction results, suggesting that energy input is not a major transmission channel. Overall, the heat map underscores how production structure and input flexibility shape the effectiveness of unconventional monetary policy under relatively higher goods demand.

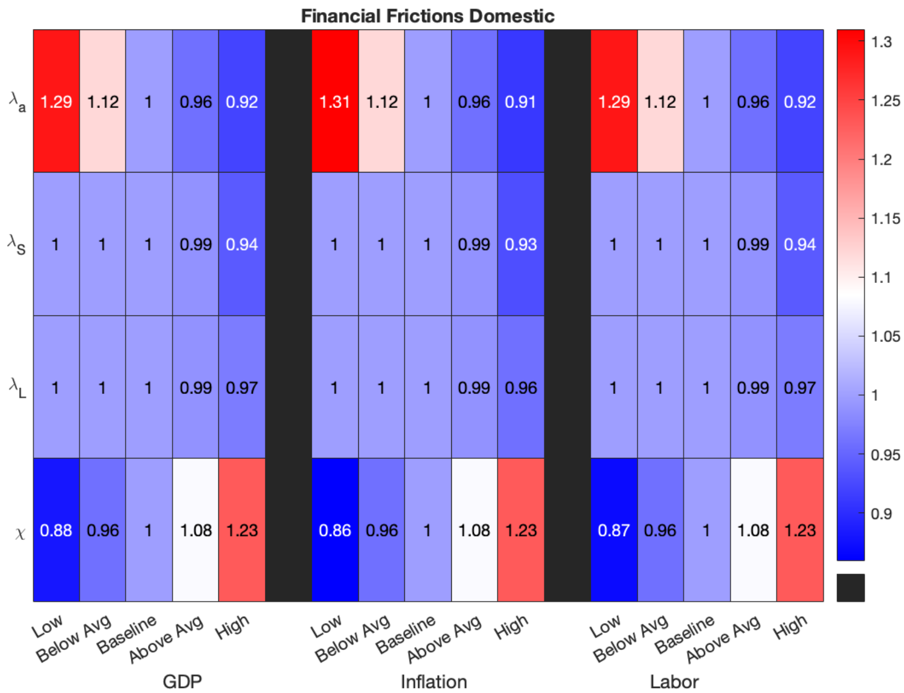
Figure 12: Firm Production Makeup Parameters and LSAP Effect with Relative High Goods Demand



Notes: The heat map shows the additional normalized effects of LSAP+ when relative goods demand is high compared to LSAP when goods demand is neutral at different structural parameter values that model firm production input levels. The chart compares the extra GDP growth, Inflation, and Hours Growth over the first year of the policy. The values are normalized to one at the posterior median parameter values.

Figure 13 displays the financial frictions heat map and illustrates how LSAP+ interaction effects vary with key financial parameters. The most prominent driver is λ_a, the elasticity of substitution between short-term and long-term bonds. The heat map shows that lower λ_a values, which indicate poor substitutability among assets, correspond to stronger LSAP+ interaction effects. LSAP conducted under a low λ_a will increase the domestic term spreads and the role of uncovered interest parity (UIP) equations in transmitting LSAP+ shocks to the goods sector. In contrast, λ_S and λ_L, which measure the elasticity of substitution between domestic and foreign bonds at short and long maturities, show minimal variation and impact, suggesting that international financial spillovers play a limited role in amplifying LSAP+ effects in this context. Finally, the financial accelerator elasticity, χ, shows a clear amplifying effect, as χ increases, so does the LSAP+ impact on asset prices and macroeconomic variables, reinforcing the idea that stronger financial frictions magnify the transmission of unconventional monetary policy conducted under relatively high goods demand.

Figure 13: Domestic Financial Frictions and LSAP Effect with Relative High Goods Demand



Notes: The heat map shows the additional normalized effects of LSAP+ when relative goods demand is high compared to LSAP when goods demand is neutral at different structural parameter values that model financial friction levels. The chart compares the extra GDP growth, Inflation, and Hours Growth over the first year of the policy. The values are normalized to one at the posterior median parameter values.

In summary, several structural features emerge as critical in shaping the interaction effects of LSAP+ relative to baseline LSAP policy. First, low substitution elasticities in consumption types and between domestic and foreign goods significantly amplify LSAP+ effects, as households are less able to reallocate spending toward sectors with lower relative prices. In contrast, higher substitution elasticities dampen the interaction, as sectoral flexibility lowers the impact of relative demand shocks. Second, the composition of firm production plays a major role, intermediate goods inputs grow in importance as they increase, while greater elasticity of production reduces the LSAP+ interaction effects on GDP and inflation. Finally, a stronger financial accelerator amplifies LSAP+ effects by increasing sensitivity to asset price movements. Together, these findings highlight how sectoral rigidity, production structure and financial transmission mechanisms shape the effectiveness of unconventional monetary policy under sectoral demand imbalances.

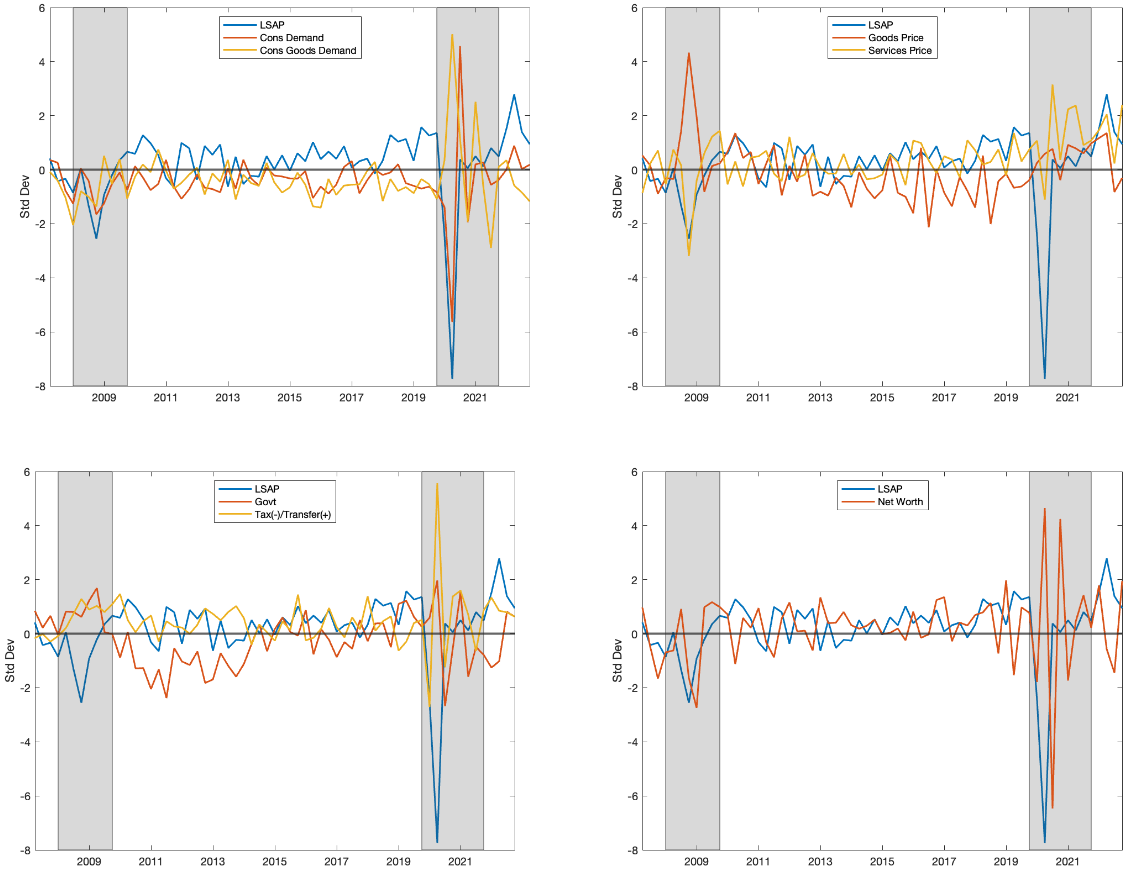
5.2 Understanding why the impact of unconventional monetary policy was so different in 2020-21 vs 2008-09

Using the interaction effects discussed previously and Figure 14 which plots the smoothed shock disturbances of the estimated model we can see why unconventional monetary policy conducted during the global financial crisis created less output growth, labor growth and inflation than the unconventional monetary policy conducted during the COVID economy and recovery period of 2020-2022. We can see that the large negative LSAP shocks (Quantitative Easing) correspond to the height of the 2008 global financial crisis and the 2020 COVID economy. However, what is different are the resulting shocks to demand, price mark-ups and transfer payments that occurred during each of these time periods.

First, the 2020 LSAP shock corresponds with a positive (negative) shock to total consumption, goods and (services) demands. However, the 2008 LSAP shocks correspond to negative (positive) shocks to total consumption goods and (services). Second, the 2008 LSAP shocks are associated with a large positive price mark-up shock to goods and negative price mark-up shocks to services, while the 2020 LSAP shocks corresponds with multiple positive service price mark-up shocks and more mild positive good price mark-up shocks. Third, in both 2008 and 2020 we see positive transfer shocks and net worth shocks; however, these shocks are much higher in the 2020 time period vs the 2008 time period.

Connecting this with the results of the previous subsection we can see that the interaction effects of each time period will be very different. In the 2020 time period, the positive total consumption demand and goods demand shocks, the positive services supply shocks, and the large positive transfer and net worth shocks will all create a bolstering effect of unconventional monetary policy to macroeconomic variables, international trade and financial markets. In contrast, in 2008, the negative total consumption shocks and good demand shocks with the negative service price mark-up shocks will all dampen the effect of unconventional monetary policy to macro variables, international trade and financial markets.

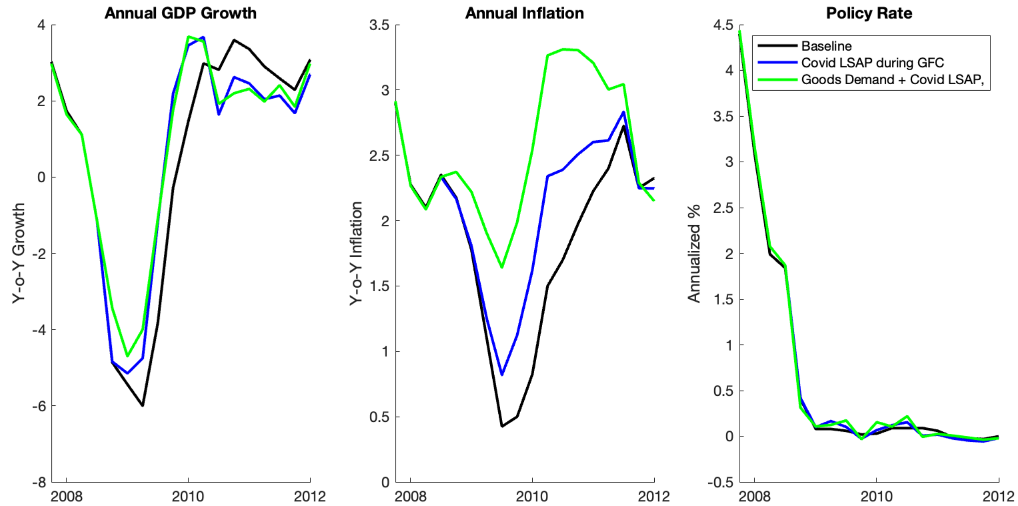
Figure 14: Select Shock Disturbances History



Notes: The figures plot the historical individual shock disturbances from the estimated model. All shocks are standardized and are calculated using the posterior mean of the estimated structural parameters. For visualization purposes we shade the time periods of 2008-2010 and 2020-2022.

We can also see the dynamics of the LSAP interaction effect when we compare some alternative economies during the GFC period. The black line in Figure 15 plots the annual GDP growth, inflation and the policy rate during the GFC. While the blue line plots the same if COVID sized LSAP shocks were conducted during the GFC. We can see that the larger LSAP shock does slightly increase GDP growth and inflation. However, the effect is greatly amplified when we look at the green line which assumes COVID sized LSAP shocks and switches the relative demand to goods from services during the same period as was seen in the 2020-2021 time period. We see that inflation would have been much larger exiting the GFC (as was the case post-COVID) if similar LSAP policy were pursued and the relative demand for goods and services would have been toward the goods sector during the GFC rather than the service sector.

Figure 15: Alternative Shocks around the GFC



Notes: The figure plots annual GDP growth, inflation and the policy rate during 2008-2012. The black line is the actual data, while the blue line plots the alternative economy if the same sized LSAP conducted in 2020 was conducted in 2008Q3-2009Q2. The green line plots the alternative economy if the same sized LSAP conducted in 2020 was conducted in 2008Q3-2009Q2 and the relative demand was higher in Goods than Services.

In all, the menu of shocks in each time period is what resulted in similar types of monetary policies creating one period of low growth and low inflation and another period of high growth and high inflation. In the following section, which discusses historical decompositions generated by the estimated model, we will see the attributed impact of unconventional monetary policy to be much larger from 2020-2022 than 2008-2010.

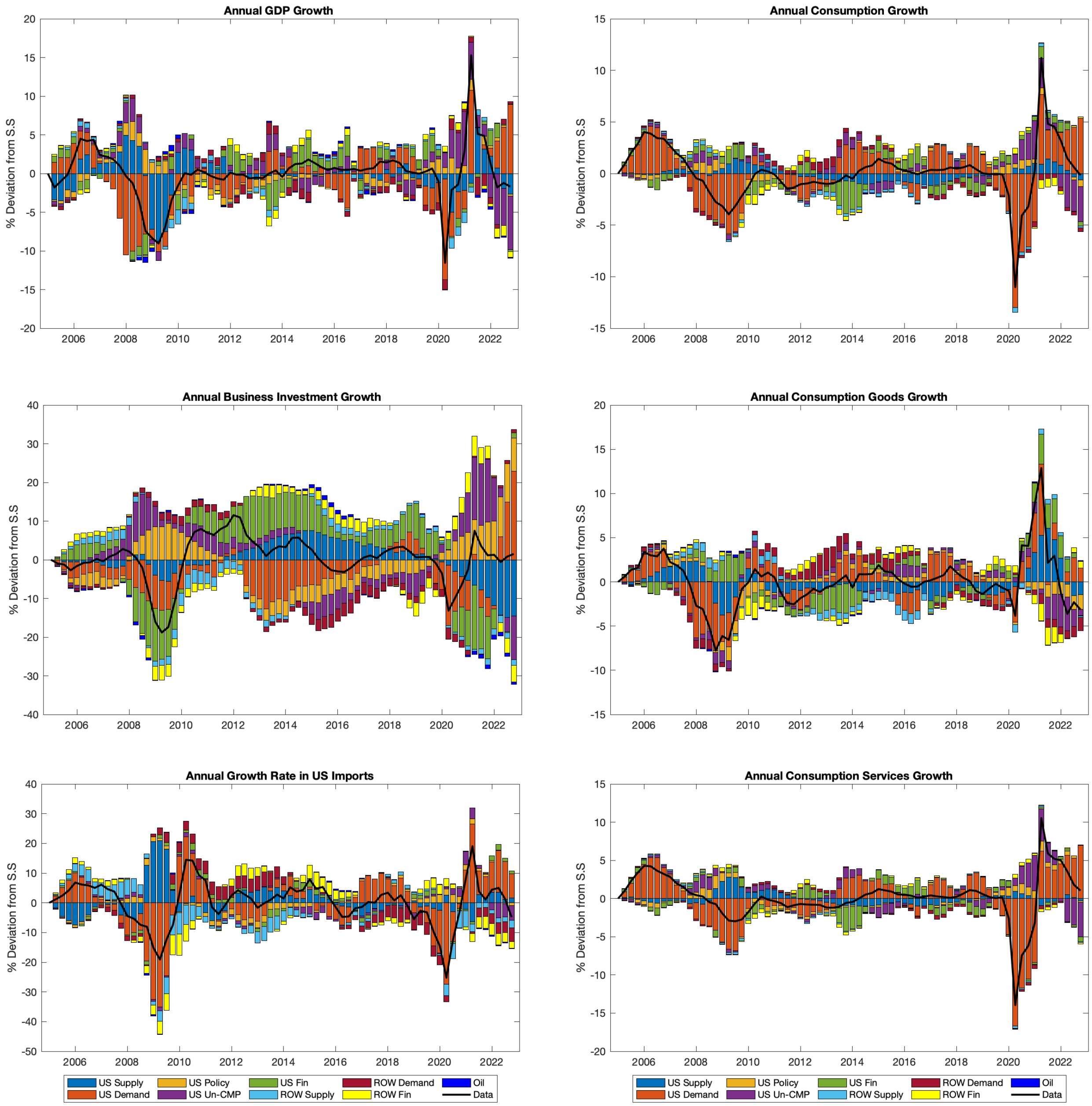
6 Historical Decompositions

In the previous sections I have described the key mechanisms determining the policy transmission effects of the model and how they interact with other key shocks in the model. The model's framework enables us to identify the source of the past fluctuations for key financial and economic variables in terms of the exogenous processes. I use historical shock decompositions to describe how the model explains the evolution of real US variables and US inflation during the global financial crisis and its recovery and compare it to the COVID economy and its recovery. Historical shock decompositions allow us key insight into two issues. They allow us to determine the impact global macro and global finance shocks have on key variables. They also allow us to determine the immediate and lasting effects various monetary and fiscal policy interventions have had on both the real economy, prices and trade.

The importance of each "type" of shock for the aforementioned variables is quantified in Figures 16 and 17. The solid line shows the variable in deviation from its steady state value. The bars represent the contribution of each type of shock to the deviation of the variable from steady state, that is, the counterfactual values each variable obtained by setting all other shocks to zero. By construction, for each quarter the bars sum to the value on the solid line. We examine nine categories of shocks. *US Supply* includes US price mark-up shocks, wage mark-up shocks and US productivity shocks in each sector. *US Demand* include US consumption and US investment shocks. *US Policy* include US policy rate, tax (transfer) and fiscal purchase shocks. *US Un-CMP* include US LSAP and Forward Guidance shocks. *US Fin* include US net worth, US risk spread shocks and includes US bond portfolio share shocks. *ROW Demand* category includes all ROW demand shocks. *ROW Supply* includes all ROW wage, price and productivity shocks. *ROW Fin* include shocks to ROW net worth, ROW risk spread and ROW bond portfolio shares and *Oil* includes all inventory and global oil supply shocks.

Figure 16 shows the decomposition of year over year growth in real GDP, consumption, goods consumption, services consumption, business investment and US imports. It illustrates the dominant role demand shocks had in both the global financial crisis and the COVID economy. Note, the large positive impact demand shocks had on consumption goods and negative impact on consumption services starting in 2020 and how this reverses in Q3 of 2021. This is line with the notion that 2020 LSAPs was conducted in a period of relatively higher demand for goods than services. Further, We can see the important role fiscal and monetary policy had on the two recovery periods; however, we can see how much more impactful unconventional monetary policy was post 2020 in stimulating GDP, business investment and services consumption than it was in 2008. In addition, the reversal (Quantitative tightening) of unconventional monetary policy in 2022Q1 has had a stronger effect than it did in 2015.

Figure 16: Historical Decompositions - US Real Variables

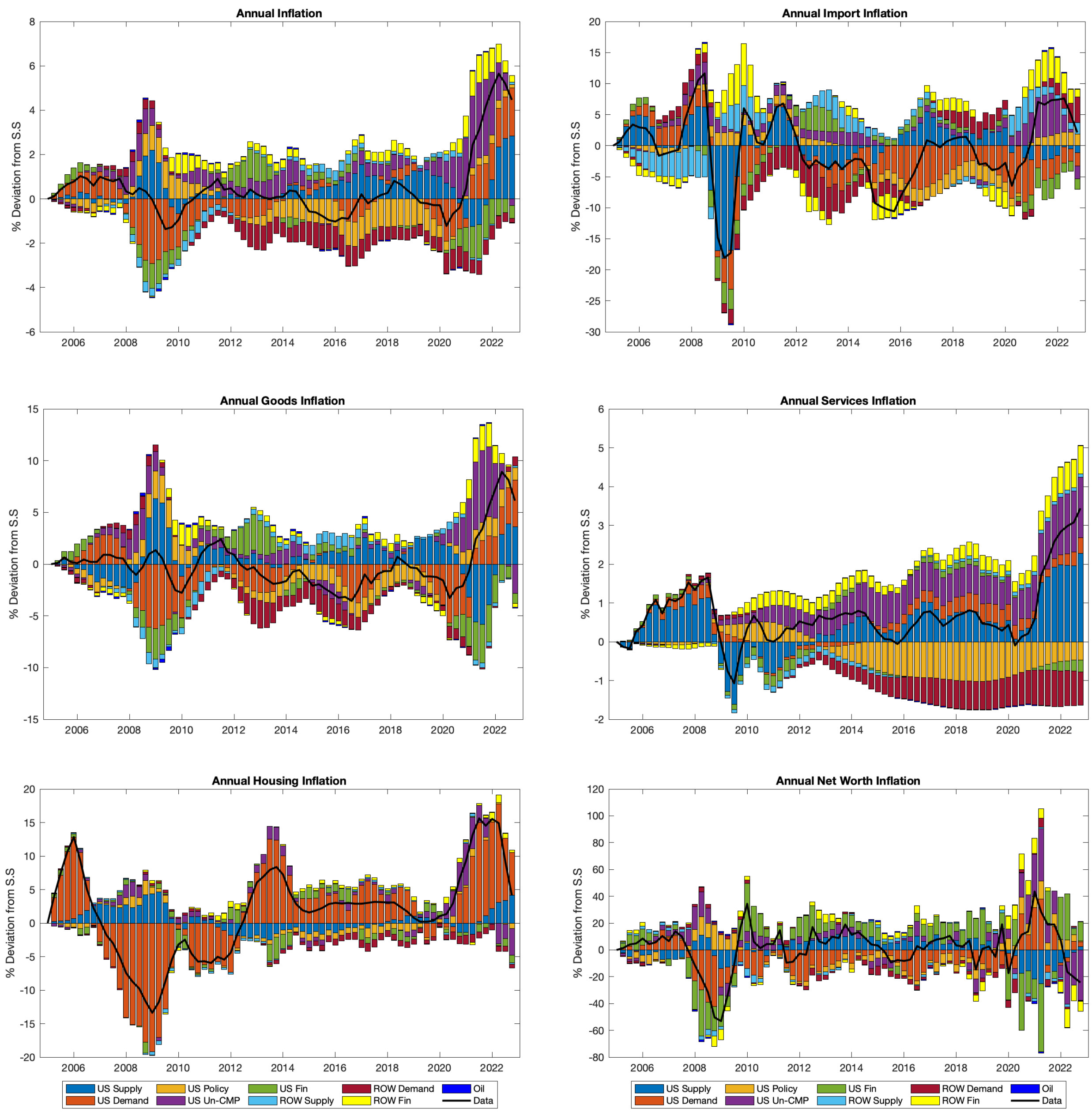


Notes: The figures plot the historical shock contributions for year over year (y-o-y) US GDP growth, Consumption growth, Consumption Goods growth, Consumption Services growth, Business Investment growth and US Import growth. The shocks are grouped into nine categories. US Supply includes US price and wage mark-up shocks and US productivity shocks in all sectors. US Demand include US consumption and US investment shocks. US Policy include US policy rate, tax and fiscal purchase shocks. US Un-CMP include US LSAP and Forward Guidance shocks. US Fin include US net worth, US risk spread shocks and US bond portfolio shocks. ROW demand includes all ROW demand shocks and ROW supply include all ROW wage, price and productivity shocks. ROW Fin include shocks to ROW net worth, ROW risk spread and ROW bond portfolio shares. Oil includes all inventory and global oil supply shocks.

In Figure 17, we turn our attention to US inflation. The structural detail of the model allows us to understand the building blocks of inflation and what factors can be pointed to as main drivers of the near 40 year high inflation seen in the US in 2022. For overall inflation, we see that the model assigns a large chunk of the inflation increase to unconventional monetary policy. The reopening of the economy turns the proportion of aggregate and relative demand shocks positively contributing to inflation and creating the environment for higher inflation throughout 2021. As the inflationary pressures of unconventional monetary policy begins to fade in late 2021, inflation remains high as domestic supply shocks begin to positively effect overall inflation and continue through 2022. By the end of 2022 the high level of inflation for the US is equally contributed to domestic demand and supply shocks with fiscal and monetary policy having a marginally negative effect. We can also see the much larger positive impact unconventional monetary policy had on inflation from 2020-2022 compared to 2008-2010. I contribute this to the interactive or state-dependent impacts of unconventional monetary policy, discussed in the previous sections that existed in 2020-2022 but did not exist in the 2008-2010 time period.

When we look at individual sectoral inflation, we see that the unconventional monetary policy significantly impacted import, goods, services, housing and asset inflation starting in 2020. Once again the positive impact for each is greater in the 2020-2022 window than the 2008-2010 window. Given the high stickiness in service inflation, the positive impact of unconventional monetary policy on services inflation maintains its large positive impact throughout the sample window. We can also see that domestic supply side shocks contributed a larger relative impact on inflation in the services sector, while demand shocks, in addition to unconventional monetary policy attributed a relative important impact in the goods and housing sectors.

Figure 17: Historical Decompositions - US Inflation



Notes: The figures plot the historical shock contributions for year over year (y-o-y) US Inflation, Import Inflation, Goods Inflation, Services Inflation, Housing Inflation and Net Worth Asset Inflation. The shocks are grouped into nine categories. US Supply includes US price and wage mark-up shocks and US productivity shocks in all sectors. US Demand include US consumption and US investment shocks. US Policy include US policy rate, tax and fiscal purchase shocks. US Un-CMP include US LSAP and Forward Guidance shocks. US Fin include US net worth, US risk spread shocks and US bond portfolio shocks. ROW demand includes all ROW demand shocks and ROW supply include all ROW wage, price and productivity shocks. ROW Fin include shocks to ROW net worth, ROW risk spread and ROW bond portfolio shares. Oil includes all inventory and global oil supply shocks.

We see that Figures 16 and 17 are consistent with the results of section 5 that showed unconventional monetary policy would have a much stronger effect on real activity, prices, and the exchange rate when it is conducted in a world of high consumption and goods demand, positive price mark-up shocks in the services sector and in a world with large fiscal transfers.

7 Conclusion

I construct and estimate a multi-sector (services, goods, housing) three-region (US, ROW, OPEC+) open-economy New Keynesian DSGE model to evaluate the drivers of inflation since 2021 and the interaction effects that occur between unconventional monetary policy, sectoral demand and sectoral supply. The model has a role for conventional monetary and fiscal policy, unconventional monetary policy, fiscal transfers, sectoral demand shifts of goods and services, a housing market, oil market and an international supply chain. These have all been pointed to as potential drivers of inflation in the post COVID recovery. The model is estimated using 61 international data series including, aggregate economic data, sectoral data, oil data, financial data, international trade data and public sector debt data.

I find that unconventional monetary policy will have different aggregate effects on output and inflation depending on the balance of relative goods and services demand, the balance of relative consumption and savings demand, the stance of fiscal policy and the relative supply shocks in the goods and services sectors. I find that the model states that the stance of all of these were very much in opposite directions when we compare them in the 2008-2010 period vs the 2020-2022 period. As a result, the effects of unconventional monetary policy in the 2008-2010 period are dampened in terms of their effect on output and inflation, while there effects are heightened in the 2020-2022 period. This helps us explain while one period is associated with low inflation and moderate growth while the other period is associated with high economic growth and inflation. In sum the developed model is able to capture the dynamics seen before 2020 and after and allows us to examine the effects of policy with a full menu of different business cycle drivers rather than focusing on only a few at a time.

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A1 Additional Figures and Tables

Table A2: Prior and Posterior Estimates - Structural Parameters

			U.S. Posterior			ROW Posterior		
Parameter		Prior	Mean	5%	95%	Mean	5%	95%
Habit Consumption	h	β(0.7,0.1)	0.44	0.37	0.52	0.25	0.18	0.30
Habit Housing Stock	h_{hou}	β(0.2,0.1)	0.38	0.25	0.50	0.27	0.06	0.50
Utilization Cost	$a''(u)$	β(0.2,0.025)	0.23	0.19	0.27	0.44	0.40	0.48
Investment Adj Cost	S''	G(5,1)	10.56	9.48	11.66	5.48	4.90	6.19
CRRA Labor	ν_l	G(2,0.25)	2.08	1.82	2.32	2.00	1.66	2.29
Elasticity:ST-LT Bonds	λ_a^{est}	β(0.5,0.1)	0.64	0.54	0.74	0.64	0.58	0.72
Elasticity:Home-Foreign ST Bonds	λ_S^{est}	β(0.5,0.1)	0.20	0.16	0.26	0.26	0.22	0.29
Elasticity:Home-Foreign LT Bonds	λ_L^{est}	β(0.5,0.1)	0.26	0.21	0.32	0.42	0.36	0.49
Taylor rule: Persistence	ρ	β(0.7,0.1)	0.93	0.91	0.94	0.93	0.92	0.94
Taylor rule: Inflation	r_π	G(2,0.2)	1.80	1.69	1.90	2.12	1.97	2.33
Taylor rule: Output gap	r_y	G(0.12,0.025)	0.06	0.04	0.08	0.05	0.03	0.06
Taylor rule: NER	r_d	N(0,0.025)	-	-	-	-0.05	-0.09	-0.02
Tax rule: Output	τ_y	G(1,0.2)	1.04	0.77	1.23	1.32	1.04	1.49
Tax rule: Debt	τ_b	G(1,0.2)	0.41	0.31	0.49	0.85	0.76	0.96
Elasticity:Home-Foreign Cons	λ_c	G(0.9,0.1)	1.13	1.05	1.22	0.10	0.08	0.11
Elasticity:Home-Foreign Inv	λ_I	G(0.9,0.1)	1.00	0.98	1.02	0.22	0.18	0.26
Elasticity:Sectoral Labor	η_l	G(0.9,0.1)	0.79	0.68	0.93	0.92	0.89	0.94
Elasticity:Goods-Services	λ_{type}	G(0.9,0.1)	0.87	0.76	0.96	0.55	0.48	0.62
Elasticity:Home-Foreign Intermed	λ_{Int}	G(0.9,0.1)	0.40	0.26	0.66	0.25	0.11	0.33
Wage Services indexation	$\iota_{w,serv}$	β(0.5,0.2)	0.11	0.05	0.18	0.13	0.07	0.21
Wage Goods indexation	$\iota_{w,goods}$	β(0.5,0.2)	0.43	0.33	0.55	0.59	0.44	0.70
Wage Housing indexation	$\iota_{w,hou}$	β(0.5,0.2)	0.23	0.11	0.36	0.26	0.13	0.38
Goods price indexation	ι_H	β(0.5,0.2)	0.66	0.57	0.72	0.84	0.82	0.86
Housing price indexation	ι_{hou}	β(0.5,0.2)	0.40	0.22	0.61	0.57	0.35	0.84
Services price indexation	ι_{serv}	β(0.5,0.2)	0.80	0.60	0.96	0.90	0.81	0.96
Import price indexation	ι_F	β(0.5,0.2)	0.31	0.18	0.46	0.80	0.69	0.91
Wage Services Adj Cost	$\kappa_{w,serv}^{est}$	β(0.5,0.1)	0.95	0.94	0.97	0.96	0.94	0.97
Wage Goods Adj Cost	$\kappa_{w,goods}^{est}$	β(0.5,0.1)	0.99	0.98	0.99	0.95	0.93	0.97
Wage Housing Adj Cost	$\kappa_{w,hou}^{est}$	β(0.5,0.1)	0.98	0.98	0.99	0.97	0.96	0.98
Goods price Adj Cost	κ_H^{est}	β(0.5,0.1)	0.82	0.78	0.85	0.77	0.73	0.81
Housing price Adj Cost	κ_{hou}^{est}	β(0.5,0.1)	0.59	0.55	0.63	0.47	0.42	0.52
Services price Adj Cost	κ_{serv}^{est}	β(0.5,0.1)	0.95	0.94	0.96	0.82	0.77	0.86
Import price Adj Cost	κ_F^{est}	β(0.5,0.1)	0.82	0.81	0.83	0.89	0.86	0.91
Financial Spread Elasticity	χ	G(0.05,0.01)	0.046	0.043	0.050	0.038	0.036	0.041
Global convenience yield of oil	$-\kappa_{oil}$	β(0.2,0.1)	0.64	0.54	0.73			

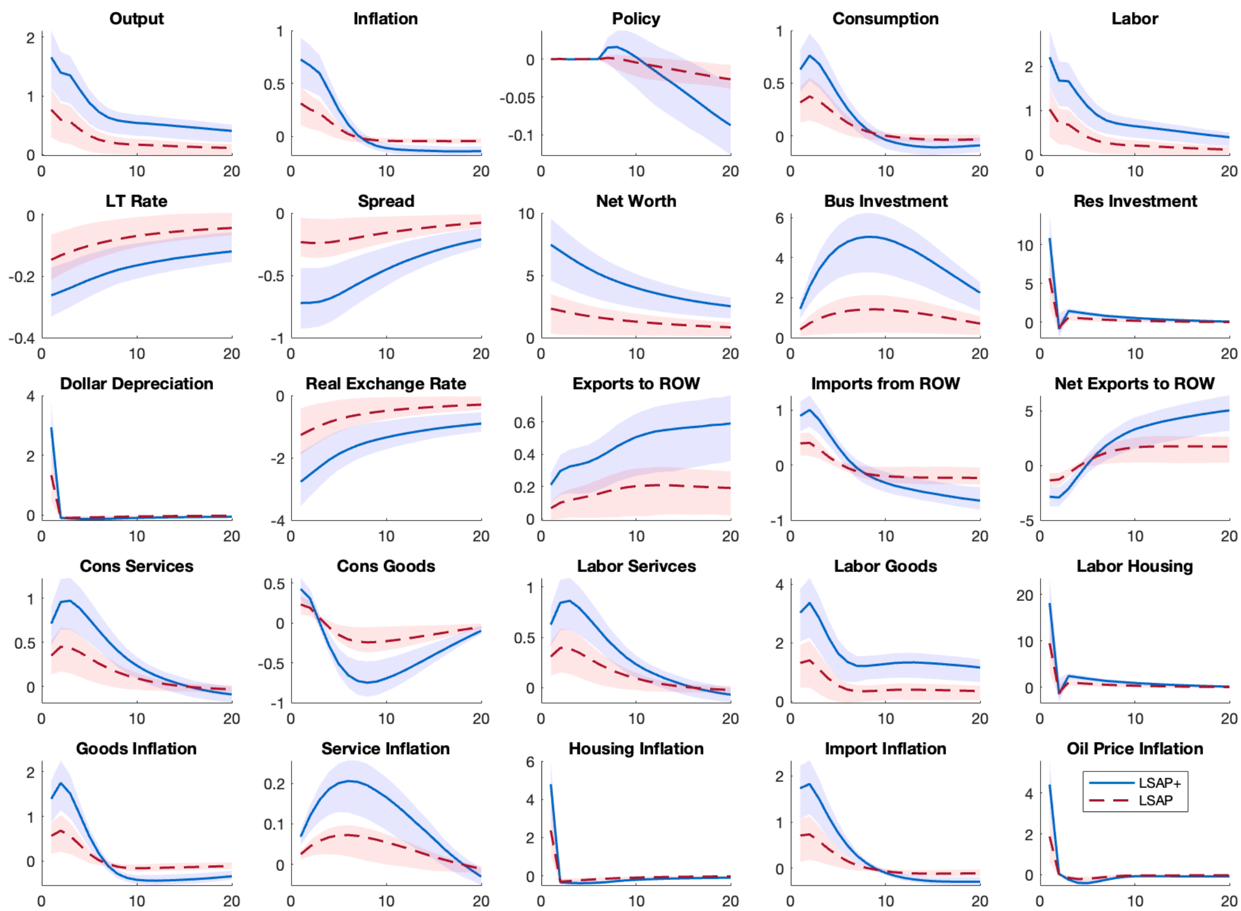
Table A3: Prior and Posterior Estimates - Exogenous Shock Parameters

Parameter		Prior	U.S. Posterior Mean	U.S. Posterior 5%	U.S. Posterior 95%	ROW Posterior Mean	ROW Posterior 5%	ROW Posterior 95%
Shock Standard Deviations (x100)								
Wage Goods Shock	$\sigma_{w,goods}$	$IG(0.5, 0.4)$	0.30	0.26	0.34	0.68	0.60	0.77
Wage Services Shock	$\sigma_{w,serv}$	$IG(0.5, 0.4)$	0.57	0.50	0.64	0.60	0.53	0.68
Wage Housing Shock	$\sigma_{w,hou}$	$IG(0.5, 0.4)$	0.45	0.40	0.51	0.48	0.42	0.56
Goods Mark-up Shock	σ_H	$IG(0.5, 0.4)$	1.12	0.96	1.30	1.19	1.01	1.39
Housing Mark-up Shock	σ_{hou}	$IG(0.5, 0.4)$	7.67	6.12	9.35	4.64	3.55	5.78
Services Mark-up Shock	σ_{serv}	$IG(0.5, 0.4)$	0.25	0.21	0.28	0.80	0.68	0.95
Import Mark-up Shock	σ_F	$IG(0.5, 0.4)$	2.45	2.17	2.76	2.11	1.85	2.42
Goods Productivity Shock	$\sigma_{a,goods}$	$IG(0.5, 0.4)$	2.09	1.84	2.36	1.75	1.56	1.96
Services Productivity Shock	$\sigma_{a,serv}$	$IG(0.5, 0.4)$	0.73	0.64	0.84	0.45	0.39	0.52
Housing Productivity Shock	$\sigma_{a,hou}$	$IG(0.5, 0.4)$	3.25	2.89	3.68	1.77	1.56	1.99
Consumption Pref Shock	σ_b	$IG(0.5, 0.4)$	5.09	4.41	5.86	3.50	3.06	3.99
Goods Consumption Shock	σ_{goods_d}	$IG(0.5, 0.4)$	1.40	1.25	1.57	1.99	1.76	2.23
Housing Demand Shock	σ_{hou_d}	$IG(0.5, 0.4)$	7.85	7.26	8.49	5.17	4.59	5.81
Investment Shock	σ_I	$IG(0.5, 0.4)$	1.29	1.06	1.55	1.57	1.32	1.83
Trade Shock	σ_{trade}	$IG(0.5, 0.4)$	5.27	4.72	5.86	-	-	-
CMP Shock	σ_r	$IG(0.5, 0.4)$	0.12	0.11	0.14	0.07	0.06	0.08
LSAP Shock	σ_{γ_b}	$IG(0.5, 0.4)$	8.78	7.96	9.61	8.12	7.30	9.01
Govt Purchases Shock	σ_g	$IG(0.5, 0.4)$	0.73	0.64	0.81	0.99	0.83	1.05
Tax Shock	σ_{tax}	$IG(0.5, 0.4)$	37.07	34.30	39.96	43.85	40.96	46.85
Net worth Shock	σ_{NW}	$IG(0.5, 0.4)$	3.52	2.98	4.06	1.47	1.26	1.68
Risk Shock	σ_{Fin}	$IG(0.5, 0.4)$	0.26	0.23	0.30	0.17	0.14	0.19
ST-LT Bond Demand Shock	σ_{γ_a}	$IG(0.5, 0.4)$	10.39	9.17	11.86	11.73	10.39	13.26
ST Home Bond Demand Shock	σ_{γ_S}	$IG(0.5, 0.4)$	1.69	1.20	2.19	2.33	1.92	2.82
LT Home Bond Demand Shock	σ_{γ_L}	$IG(0.5, 0.4)$	2.80	2.09	3.72	1.37	1.12	1.64
Oil Supply Fringe Shock	$\sigma_{supply,fringe}$	$IG(0.5, 0.4)$	1.69	1.49	1.92	-	-	-
Oil Supply OPEC+ Shock	$\sigma_{supply,dom}$	$IG(0.5, 0.4)$	6.64	5.92	7.31	-	-	-
Oil Inventory Shock	$\sigma_{oil_{inv}}$	$IG(0.5, 0.4)$	8.85	7.69	10.58	-	-	-
Shock Persistences								
Goods Productivity Shock	$\rho_{a,goods}$	$\beta(0.5, 0.2)$	0.92	0.88	0.95	0.91	0.87	0.94
Services Productivity Shock	$\rho_{a,serv}$	$\beta(0.5, 0.2)$	0.99	0.98	0.99	0.88	0.81	0.94
Housing Productivity Shock	$\rho_{a,hou}$	$\beta(0.5, 0.2)$	0.92	0.89	0.94	0.89	0.84	0.93
Consumption Shock	ρ_b	$\beta(0.5, 0.2)$	0.92	0.89	0.94	0.95	0.94	0.96
Goods Consumption Pref Shock	ρ_{goods_d}	$\beta(0.5, 0.2)$	0.98	0.96	0.98	0.85	0.79	0.90
Housing Demand Shock	ρ_{hou_d}	$\beta(0.5, 0.2)$	0.98	0.97	0.98	0.98	0.96	0.98
Investment Shock	ρ_I	$\beta(0.5, 0.2)$	0.59	0.51	0.68	0.67	0.58	0.75
Trade Shock	ρ_{trade}	$\beta(0.5, 0.2)$	0.87	0.85	0.89	-	-	-
LSAP Shock	ρ_{γ_b}	$\beta(0.5, 0.2)$	0.88	0.84	0.93	0.98	0.96	0.99
Govt Purchase Shock	ρ_g	$\beta(0.5, 0.2)$	0.99	0.98	0.99	0.77	0.70	0.83
Tax Shock	ρ_{tax}	$\beta(0.5, 0.2)$	0.07	0.04	0.09	0.04	0.03	0.05
Net worth Shock	ρ_{NW}	$\beta(0.5, 0.2)$	0.20	0.09	0.31	0.36	0.26	0.43
Risk Shock	ρ_{Fin}	$\beta(0.5, 0.2)$	0.64	0.57	0.72	0.70	0.65	0.75
ST-LT Bond Demand Shock	ρ_{γ_a}	$\beta(0.5, 0.2)$	0.97	0.96	0.98	0.95	0.94	0.96
ST Home Bond Demand Shock	ρ_{γ_S}	$\beta(0.5, 0.2)$	0.94	0.88	0.98	0.99	0.98	0.99
LT Bond Demand Shock	ρ_{γ_L}	$\beta(0.5, 0.2)$	0.99	0.98	0.99	0.99	0.99	0.99
Oil Supply Fringe Shock	$\rho_{supply,fringe}$	$\beta(0.5, 0.2)$	0.94	0.91	0.96	-	-	-
Oil Supply OPEC+ Shock	$\rho_{supply,dom}$	$\beta(0.5, 0.2)$	0.65	0.54	0.75	-	-	-
Oil Inventory Shock	$\rho_{oil_{inv}}$	$\beta(0.5, 0.2)$	0.73	0.61	0.85	-	-	-
Shock Correlations								
Net worth Shock Corr	ρ_{NW,NW^*}	$\beta(0.5, 0.1)$	0.49	0.44	0.56	-	-	-
Risk Shock Corr	ρ_{Fin,Fin^*}	$\beta(0.5, 0.1)$	0.58	0.48	0.66	-	-	-

Table A4: Parameter Sensitivity Values used to Construct Heat Maps

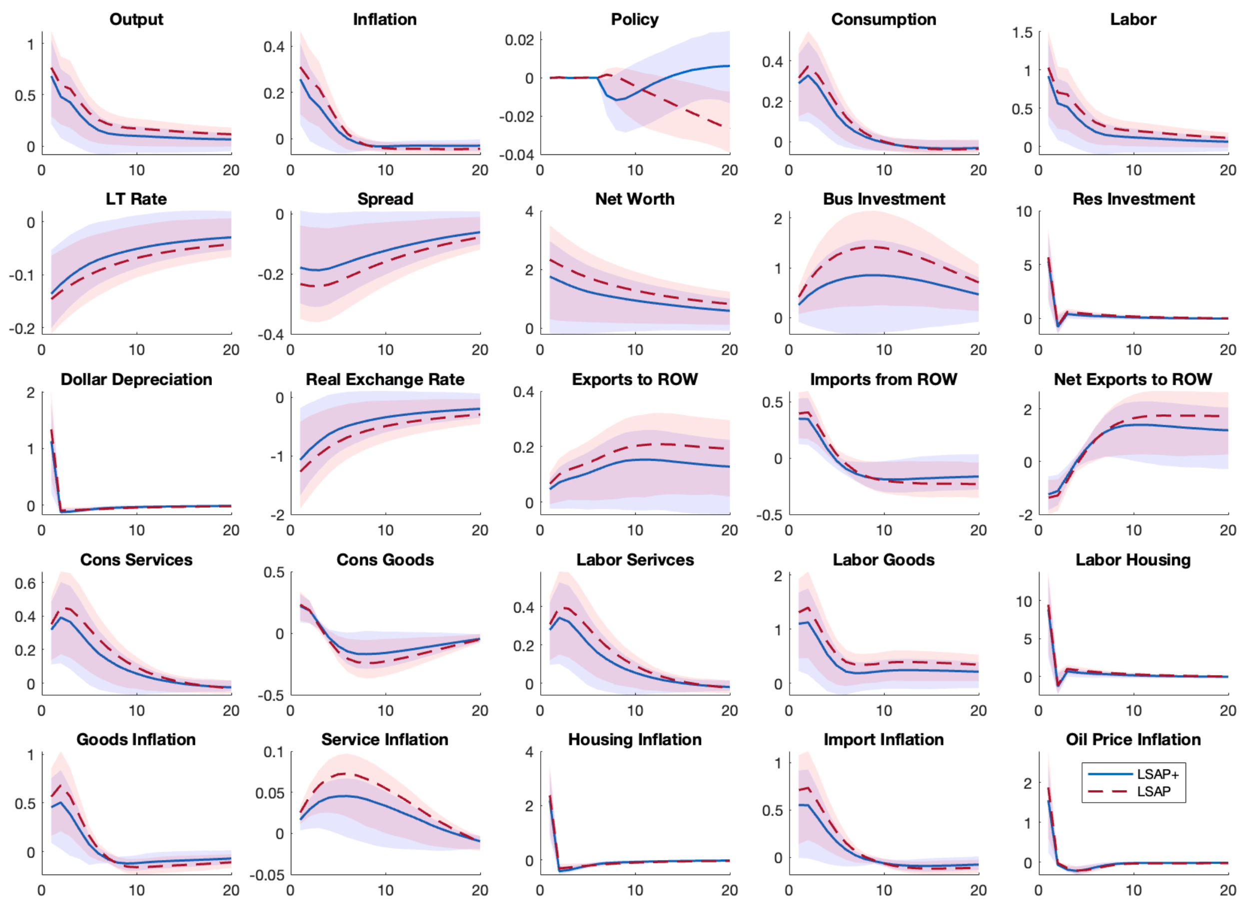
		Low	Below Avg	Baseline	Above Avg	High
Services price Adj Cost	κ_{serv}^{est}	0.5	0.7	0.95	0.975	0.99
Goods price Adj Cost	κ_{H}^{est}	0.5	0.7	0.82	0.9	0.99
Import price Adj Cost	κ_{F}^{est}	0.5	0.7	0.82	0.9	0.99
Services price Indexation	ι_{serv}	0.25	0.5	0.8	0.9	0.95
Goods price Indexation	ι_{H}	0.25	0.5	0.66	0.7	0.95
Import price Indexation	ι_{F}	0.05	0.1	0.31	0.7	0.95
Elasticity:Home-Foreign Cons	λ_c	0.1	0.5	1.13	1.5	3
Elasticity:Home-Foreign Inv	λ_I	0.1	0.5	1.0	1.5	3
Elasticity:Goods-Services	λ_{type}	0.1	0.5	0.87	1.5	3
Elasticity:Home-Foreign Intermediates	λ_{Int}	0.1	0.25	0.4	1.5	3
Elasticity: Goods factor inputs	τ_{goods}	0.1	0.15	0.225	0.5	1.0
Capital share of Goods production	α_K	0.1	0.35	0.45	0.55	0.6
Share of Intermediate Goods in Goods	$\alpha_{M,goods}$	0.01	0.1	0.25	0.4	0.5
Share of Intermediate Services in Services	$\alpha_{M,serv}$	0.01	0.05	0.1	0.2	0.3
Share of Intermediate Goods in Services	$\alpha_{M,goods,serv}$	0.01	0.05	0.1	0.2	0.3
Share of Oil in Goods sector	$\alpha_{O,goods}$	0.01	0.03	0.06	0.1	0.15
Elasticity:ST-LT Bonds	λ_a^{est}	0.3	0.45	0.64	0.75	0.9
Elasticity:Home-Foreign ST Bonds	λ_S^{est}	0.05	0.1	0.2	0.6	0.9
Elasticity:Home-Foreign LT Bonds	λ_L^{est}	0.05	0.1	0.26	0.6	0.9
Financial Spread Elasticity	χ	0.025	0.04	0.046	0.06	0.1

Figure A18: Unconventional Monetary Policy with a Consumption Demand Shock



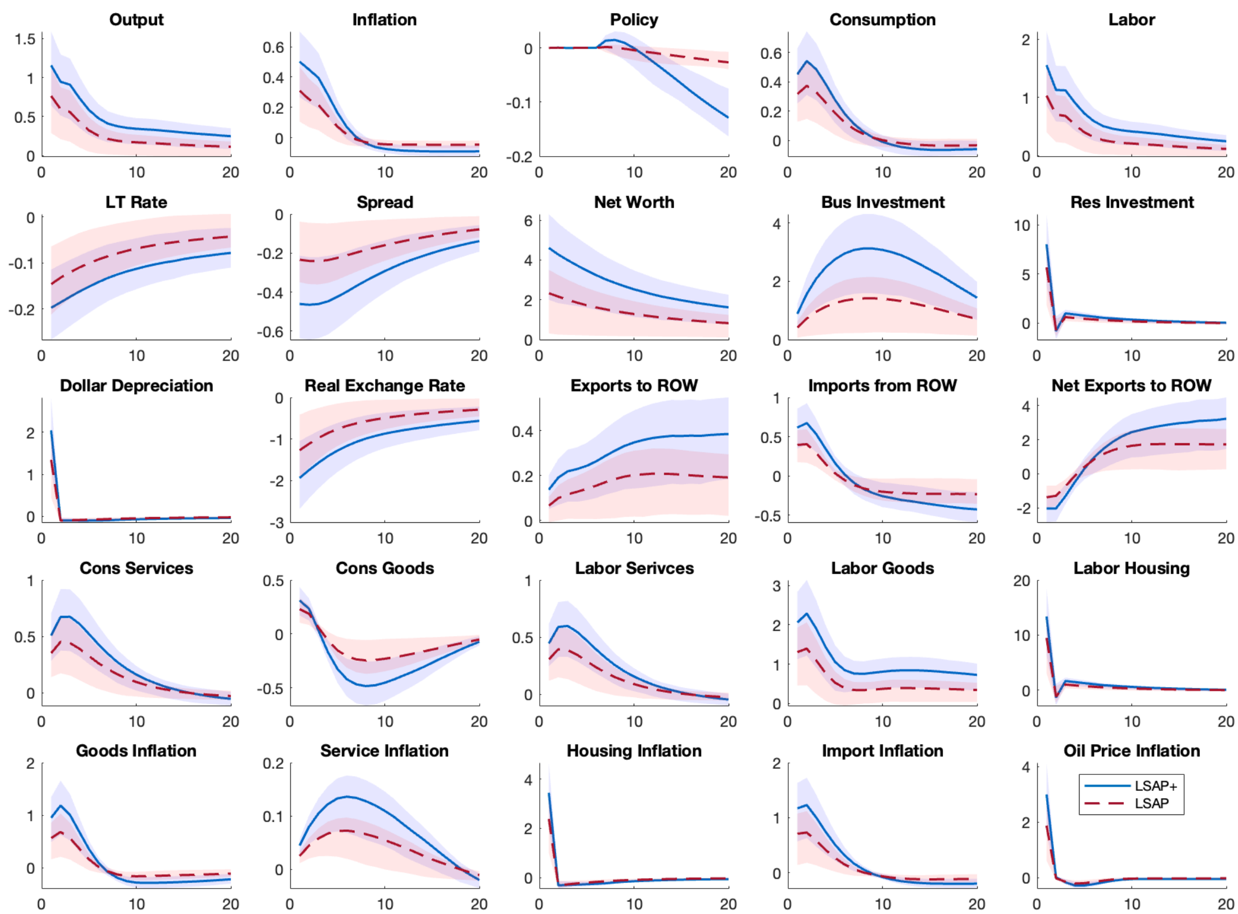
Notes: The dashed red line plots the response of an LSAP shock equivalent to a long-term asset purchase of 1.5% of steady state GDP by the central bank with a year's long commitment of keeping the policy rate unchanged. The solid blue line plots the impact of that same LSAP purchase and commitment with a concurrent shock to total consumption demand after the dynamics of a stand-alone total consumption demand shock are subtracted away. All responses plot the % deviation away from each variable's respected steady state value on the y-axis. All interest rate and inflation rates are annualized.

Figure A19: Unconventional Monetary Policy with a Goods Supply Mark-up Shock



Notes: The dashed red line plots the response of an LSAP shock equivalent to a long-term asset purchase of 1.5% of steady state GDP by the central bank with a year's long commitment of keeping the policy rate unchanged. The solid blue line plots the impact of that same LSAP purchase and commitment with a concurrent shock to goods prices after the dynamics of a stand-alone goods mark-up shock are subtracted away. All responses plot the % deviation away from each variable's respected steady state value on the y-axis. All interest rate and inflation rates are annualized.

Figure A20: Unconventional Monetary Policy with a Net Worth Shock



Notes: The dashed red line plots the response of an LSAP shock equivalent to a long-term asset purchase of 1.5% of steady state GDP by the central bank with a year's long commitment of keeping the policy rate unchanged. The solid blue line plots the impact of that same LSAP purchase and commitment with a concurrent positive shock to net worth after the dynamics of a stand-alone positive shock to net worth are subtracted away. All responses plot the % deviation away from each variable's respected steady state value on the y-axis. All interest rate and inflation rates are annualized.