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

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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, LSAP's 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 LSAP's 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. Further, out-of-sample forecasts conducted show the importance of modeling multiple sectors of the economy as well as modeling unconventional monetary policy over the last 15 years when it comes to forecasting real and nominal variables.

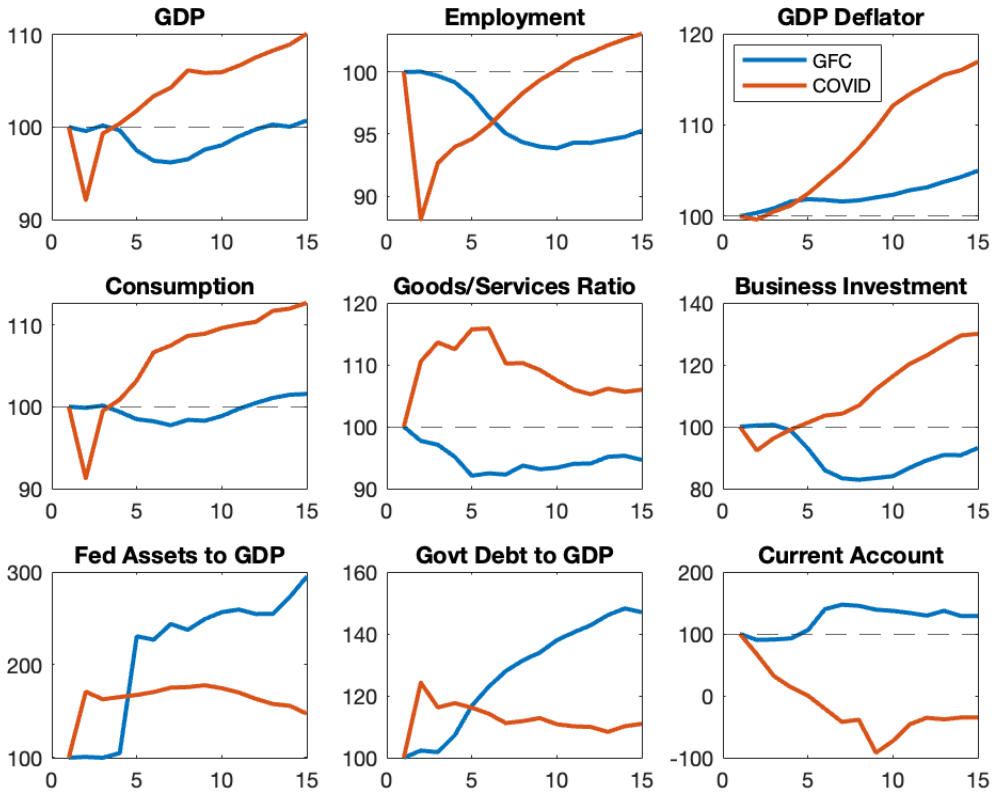
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1 Introduction

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 is associated with a prolonged decline in employment, consumption and business investment, a decline in the ratio of goods to services consumption, an increase in the current account and low and stable price growth. While the COVID economy is associated with strong growth in employment, consumption and business investment, an increase in the ratio of goods to services consumption, a decrease in the current account and inflation levels not seen in more than forty years.

This paper builds a multi-sector three-region open-economy New-Keynesian dynamic stochastic general equilibrium (DSGE) model to account for the different dynamics associated with both these episodes. The model includes tradable-goods, non-tradable services and a housing sector with aggregate and relative sectoral supply and demand shocks. In addition, the model includes an international bond portfolio which allows the monetary authority to conduct both conventional and unconventional monetary policy. The model has both fiscal expenditure policy and fiscal transfer policy, an endogenous oil sector and an endogenous international financial market. The model is estimated using over 60 international data series that include aggregate macroeconomic variables, sectoral variables, financial variables, international trade variables and oil price and supply variables.

Given its detail, the model 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. In particular, the model is able to shed light on eight key stories 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. This is due to the fact that I find that unconventional monetary policy is most expansionary in real and nominal terms when many of 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.

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) and oil as production factors, the service sector produces non-tradable services that rely only on labor 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 the multiple regions allows for international spillovers in terms of economic shocks, exchange rate and trade effects, and global unconventional monetary policy. The inclusion of the financial market and multiple bond markets (international bond portfolio) allows for analysis to be done on large-scale asset purchases in both the US and global bond markets and US and global equity markets. Finally, the model includes an endogenous oil market with an oil dominant producer (OPEC+) that creates both endogenous oil demand and endogenous OPEC+ oil supply.

I find that all of these are key modeling features that increase the forecasting ability of the model in both the pre and post COVID economies. In particular, the nature of the paper's baseline model allows us to turn individual modeling techniques on and off and then examine the forecasting ability of the smaller nested model. I find that the baseline model is best at forecasting the macroeconomy and matching key empirical moments and co-movements. 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.

Further, many aspects of my paper relate to the supply chain network open-economy modeling techniques that have been developed in di Giovanni et al. (2022, 2023), La'O and Tahbaz-Salehi (2022), and Pasten et al. (2020, 2024) in order to explain the supply chain disturbances that occurred after the economy re-opened. In Comin et al. (2023) a multi-sector open-economy model with temporarily binding domestic and foreign supply chain constraints was developed. 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.

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.

In addition to open-economy, multi-sector, production network and oil sector modeling, 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.

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 role of fiscal policy and fiscal transfers is included in the model which di Giovanni et al. (2023) attribute as much as 1/3 of the US inflation increase.

The endogenous oil sector in the paper's model examines the role the energy crisis after the Russian invasion of Ukraine had on US and global inflation, a main inflation driver seen in Gagliardone and Gertler (2023) and Pasimeni (2022). Further, the large menu of demand and supply shocks in the paper's model allows us to evaluate the role of supply and demand shocks had on inflation in the US and the global economy, as was done with disaggregated price data in Rubbo (2024) and Shapiro (2024).

My paper contributes the 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 an international intermediate factor, 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. Notably the developed model allows us to understand why similar policy conducted during the global financial crisis

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.

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 compares the dynamics associated with a large menu of shocks included in the model. Further, the section examines the heterogenous macroeconomic effects policy shocks can have depending on the current state of the economy. Section 5 presents historical shock decompositions for various macro-financial variables of the model . Section 6 evaluates the forecasting ability of the model around 2020 and compares it to forecasts by the Survey of Professional Forecasters (SPF). This section also evaluates the importance of the inclusion of various modeling techniques into the DSGE model for forecasting GDP, inflation and international trade since 2010. 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, an oil dominant economy is introduced as a third region into the model as described in Khalil (2022). Third, a housing sector with housing capital is implemented into the model. Finally, goods production and service production include sector specific labor, capital, intermediate goods and oil nested into a CES production process. 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 provides 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:

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

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 captures 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, $c_{serv,t}$:

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

where γ_{serv} 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 Δ_{hou} determines the share of 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:

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

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,

[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.

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 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 $\iota_{w,jj}$ determines 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 a short-term and long-term uncovered interest rate parity (UIP) condition.

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

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

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]The effect of domestic unconventional monetary policy in regards 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 parameter 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).

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 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 production process:

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

where K_t is utilized capital[3], $Oil_{goods,t}$ is the oil factor of production by the domestic goods sector 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:

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

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, 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 and capital can be combined and linearized to relate capital, labor and oil demand.

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

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

[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:

$$\hat{\pi}_{H,t} - \iota_H \hat{\pi}_{H,t-1} = \beta E_t[\hat{\pi}_{H,t+1} - \iota_H \hat{\pi}_{H,t}] - \frac{\Theta_H - 1}{\kappa_H} \left(\hat{p}_{H,t} - \hat{MC}_{goods,t} \right) + \hat{e}_{H,t} \tag{27}$$

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

$$\hat{MC}_{goods,t} = (1 - \alpha_K - \alpha_{O,goods})\hat{w}_{goods,t} + \alpha_K \hat{r}^k_t + \alpha_{O,goods}\hat{p}_{oil,t} - \hat{e}_{a,goods,t} \tag{28}$$

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:

$$y_{serv,t}(i) = e_{a,serv,t} \left[(1 - \alpha_{O,serv})^{\frac{1}{\tau_{serv}}} L_{serv,t}^{\frac{\tau_{serv}-1}{\tau_{serv}}} + \alpha_{O,serv}^{\frac{1}{\tau_{serv}}} Oil_{serv,t}^{\frac{\tau_{serv}-1}{\tau_{serv}}} \right]^{\frac{\tau_{serv}}{\tau_{serv}-1}} \tag{29}$$

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

$$y_{hou,t}(i) = e_{a,hou,t} \left[(1 - \alpha_{land})^{\frac{1}{\tau_{hou}}} L_{hou,t}^{\frac{\tau_{hou}-1}{\tau_{hou}}} + \alpha_{land}^{\frac{1}{\tau_{hou}}} Land^{\frac{\tau_{hou}-1}{\tau_{hou}}} \right]^{\frac{\tau_{hou}}{\tau_{hou}-1}} \tag{30}$$

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 form the domestic economy and the ROW economy. Oil production of the dominant producer follows a the following Cobb-Douglas technology

$$Oil_{supply,dom,t} = e_{a,oil,dom,t} L_{oil,dom,t}^{\alpha_{L,oil,dom}} X_{oil,dom,t}^{\alpha_{x,dom}} \tag{31}$$

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

$$Oil_{goods,t}+Oil_{serv,t}+Oil^*_{goods,t}+Oil^*_{serv,t}+Oil_{inv,t}-Oil_{inv,t-1} = Oil_{supply,dom,t}+Oil_{supply,fringe,t} \tag{32}$$

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.

$$\hat{R}_t = \rho\hat{R}_{t-1} + (1-\rho)\left[r_\pi\hat{\pi}_t + r_y\hat{y}_t + r_d\hat{d}_t\right] + \hat{\varepsilon}_{r,t} + \sum_{k=1}^{5}\hat{e}^r_{k,t-k} \tag{33}$$

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

$$g_t + \frac{R_{t-1}}{\pi_t} b_{S,t-1} + \frac{R_{L,t}}{\pi_t} q_{L,t} b_{L,t-1} = \frac{Tax_t}{P_t} + b_{S,t} + q_{L,t} b_{L,t} \tag{34}$$

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:

$$\frac{Tax_t}{P_t} = \frac{tax}{y} \left(\frac{y_t}{y} \right)^{\tau_y} \left(\frac{b_{S,t-1} + q_{L,t-1} b_{L,t-1}}{b_S + q_L b_L} \right)^{\tau_b} e_{tax,t} \tag{35}$$

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;

$$\gamma_{b,t} = \frac{q_{L,t} b_{L,t}}{b_{S,t}} \tag{36}$$

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 consumption in services ($c_{serv,t}$), 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:

$$y_t = c_{H,t} + I_{H,t} + c_{serv,t} + HI_t + g_t + y^*_{F,t} + y_{F,dom,t} + a(u_t)\bar{K}_{t-1} \tag{37}$$

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 region's imports of consumption and oil producing goods; hence together the domestic regions's exports.

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

$$y_{F,t} = c_{F,t} + I_{F,t} \tag{38}$$

Like assets, final consumption goods and investment goods 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:

$$b_{S,t} = \frac{B_{H,S,t}}{P_t} + \frac{B^*_{F,S,t}}{P_t} \quad \& \quad q_{L,t}b_{L,t} = \frac{q_{L,t}B_{H,L,t}}{P_t} + \frac{q_{L,t}B^*_{F,L,t}}{P_t} \tag{39}$$

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:

$$(e_t B_{F,S,t} - e_t R^*_{t-1} B_{F,S,t-1}) + (e_t q^*_{L,t} B_{F,L,t} - e_t R^*_{L,t} q^*_{L,t-1} B_{F,L,t-1}) \\ - (B^*_{F,S,t} - R_{t-1} B^*_{F,S,t-1}) - (q_{L,t} B^*_{F,L,t} - R_{L,t} q_{L,t-1} B^*_{F,L,t-1}) = P_{H,t} y^*_{F,t} - e_t P^*_{H,t} y_{F,t} \tag{40}$$

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

$$Q_t \bar{K}_t = NW_t + ldr_t Dep_t \tag{41}$$

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 shock. There are seven region specific i.i.d. supply shocks to sectoral wages, sectoral domestic prices, and import prices, 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 five anticipated monetary policy shocks in

[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.

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 were 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):

$$\text{Federal Funds Rate}^{Exp}_{t,t+1} = 400R + \Lambda_R G(\theta)^1 S_t \tag{42}$$

$$\vdots \tag{43}$$

$$\text{Federal Funds Rate}^{Exp}_{t,t+5} = 400R + \Lambda_R G(\theta)^5 S_t \tag{44}$$

where $\text{Federal Funds Rate}^{Exp}_{t,t+k}$ 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. 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, 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 corresponds 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) and (γ_I) 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^*) and (γ_I^*) 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 is 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 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 A4 and A5 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 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 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

[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

$$\kappa_j = \frac{(\Theta_j - 1)\kappa_j^{est}}{(1 - \kappa_j^{est})(1 - \beta\kappa_j^{est})} \tag{45}$$

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:

$$\lambda_j = \frac{\lambda_j^{est}}{1 - \lambda_j^{est}} \tag{46}$$

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 . 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

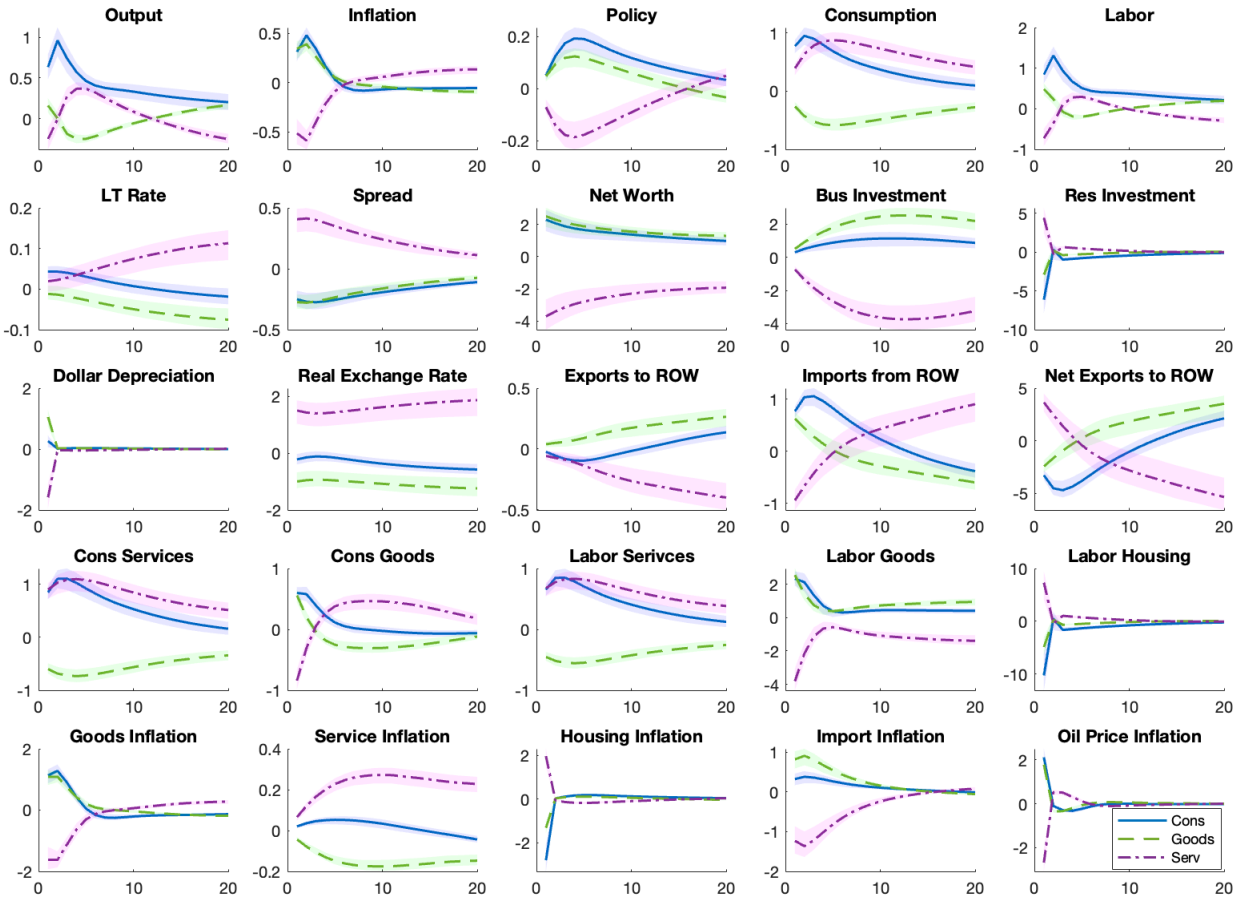
This section discusses impulse response functions (IRFs) for selected shocks that are pointed to as common disturbances of the pandemic and the recovery period. We will see that many of these shocks indeed contribute to the dynamics of both real and nominal variables of this period according to the estimated 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. In particular, we will examine consumer demand shocks, sector specific demand shocks, sector specific supply-side price shocks, as well as fiscal and monetary policy shocks.

4.1 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 shock while the dashed green line plots a goods consumption shock and the dashed purple line plots a service consumption shock. The latter two are scaled to match the effects of the aggregate consumption shock in their respective consumption sector. The aggregate consumption shock is typical, creating demand-pull growth in overall inflation and output and in each of the goods and services sector. Hours worked increases in the aggregate and in the goods and services sector. The extra domestic demand causes an increase in imports, oil and business investment.

[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.

Figure 2: Consumption Demand Shocks



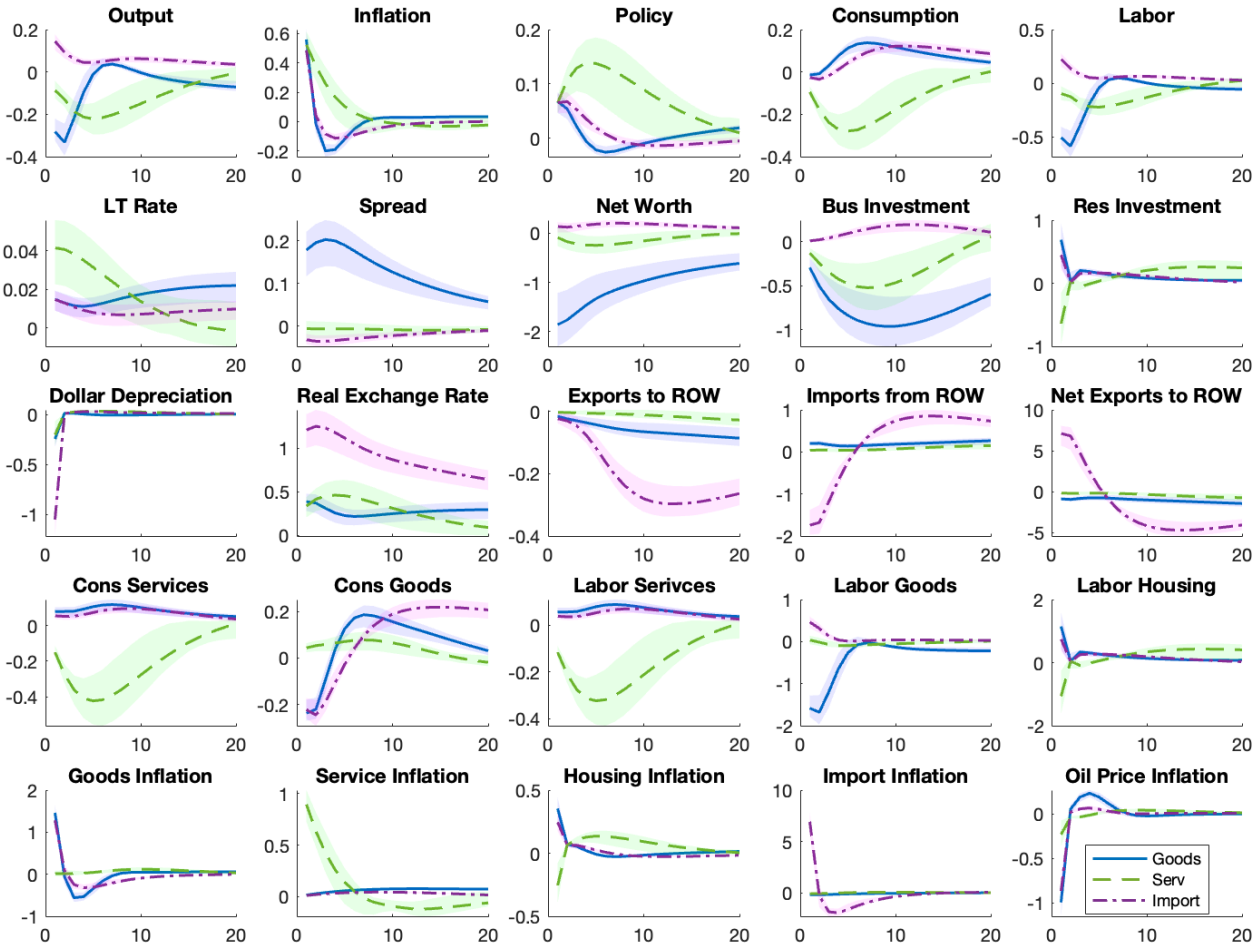
Notes: The solid blue line plots a positive aggregate consumption shock while the dashed green line plots a positive goods consumption shock and the dashed purple line plots a positive service consumption shock. The consumption shock size corresponds to a one estimated standard deviation, while the sector 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.

When examining the sector specific demand shocks we see that they are demand-pull in their specific sectors but cause a decrease in both output and prices in the opposite sector. Given the different structural parameters and input needed in the two sectors this causes different aggregate effects. We see that demand for goods shock is inflationary and slightly contractionary after 2 quarters due to the fall of overall consumption and the decrease in overall hours worked in services. The opposite is true for a positive consumption services shock, the fall in prices in the goods sector far outweighs the gain in prices in the service sector and thus creates a deflationary environment as well as an eventual increase in consumption, output and hours worked. The lower relative demand for goods lowers demand for imports,

business investment and oil.

Supply-side price shocks–Figure 3 plots the effects of positive price shocks in the goods, services and import sectors. The supply-side shock to services creates the most persistent increase in aggregate inflation lasting about 8 quarters while the other two shocks see inflation return to steady state after 3 to 4 quarters. The contractionary effects of the sector price shocks are most persistent in consumption, output and labor after the price shock occurs in the services sector.

Figure 3: Price Shocks



Notes: The solid blue line plots a positive price shock in the goods sector, while the dashed green line plots a positive price shock in the service sector and the dashed purple line plots a positive price shock to imports. The price 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 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 shock creates similar dynamics as a domestic goods price shock by

increasing goods inflation and overall inflation but the import price shock is slightly expansionary for aggregate output and labor as the rise in import prices and resulting decline in imports, stimulates domestic goods demand causing an increase in labor, output and domestic goods production.

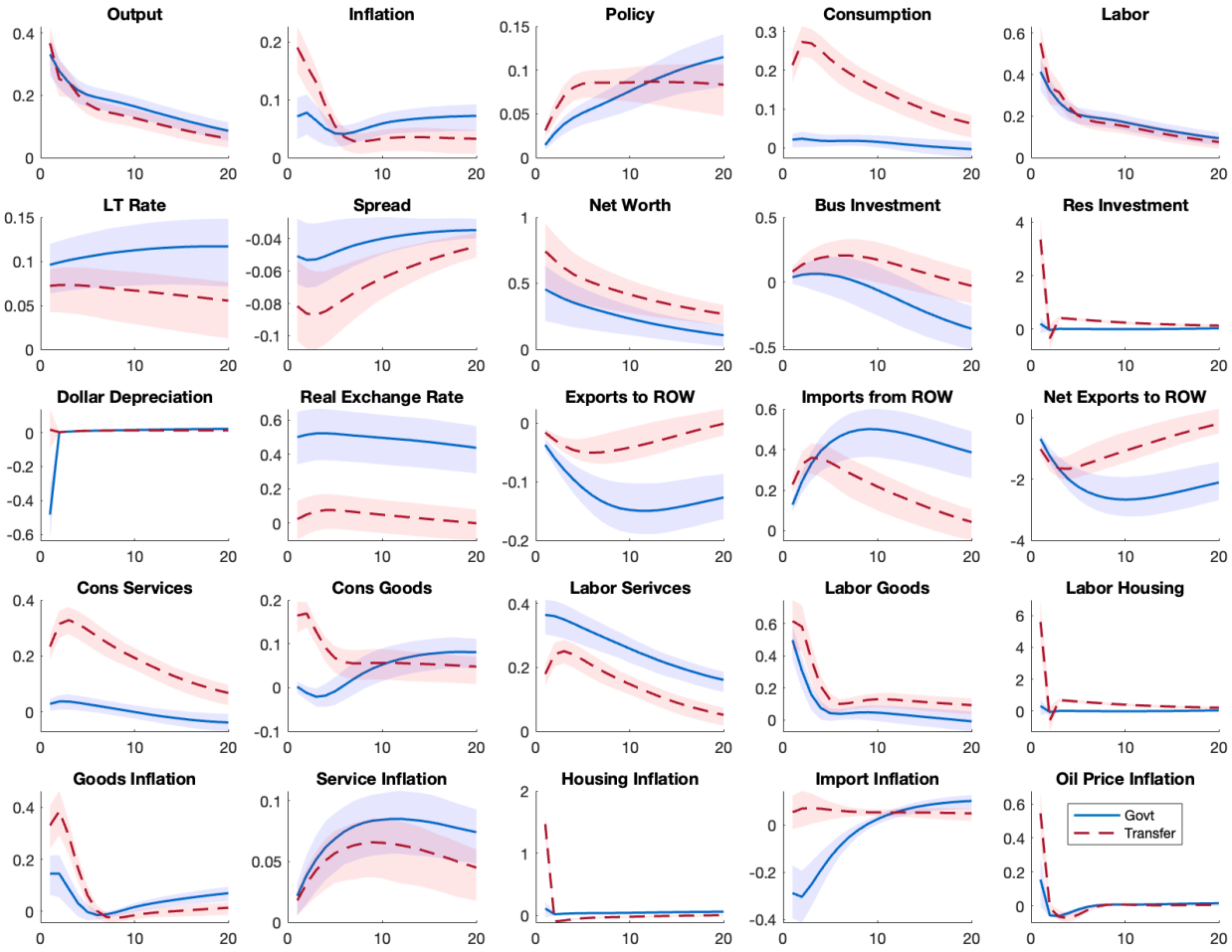
4.2 Fiscal and Monetary Policy Shocks

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 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.

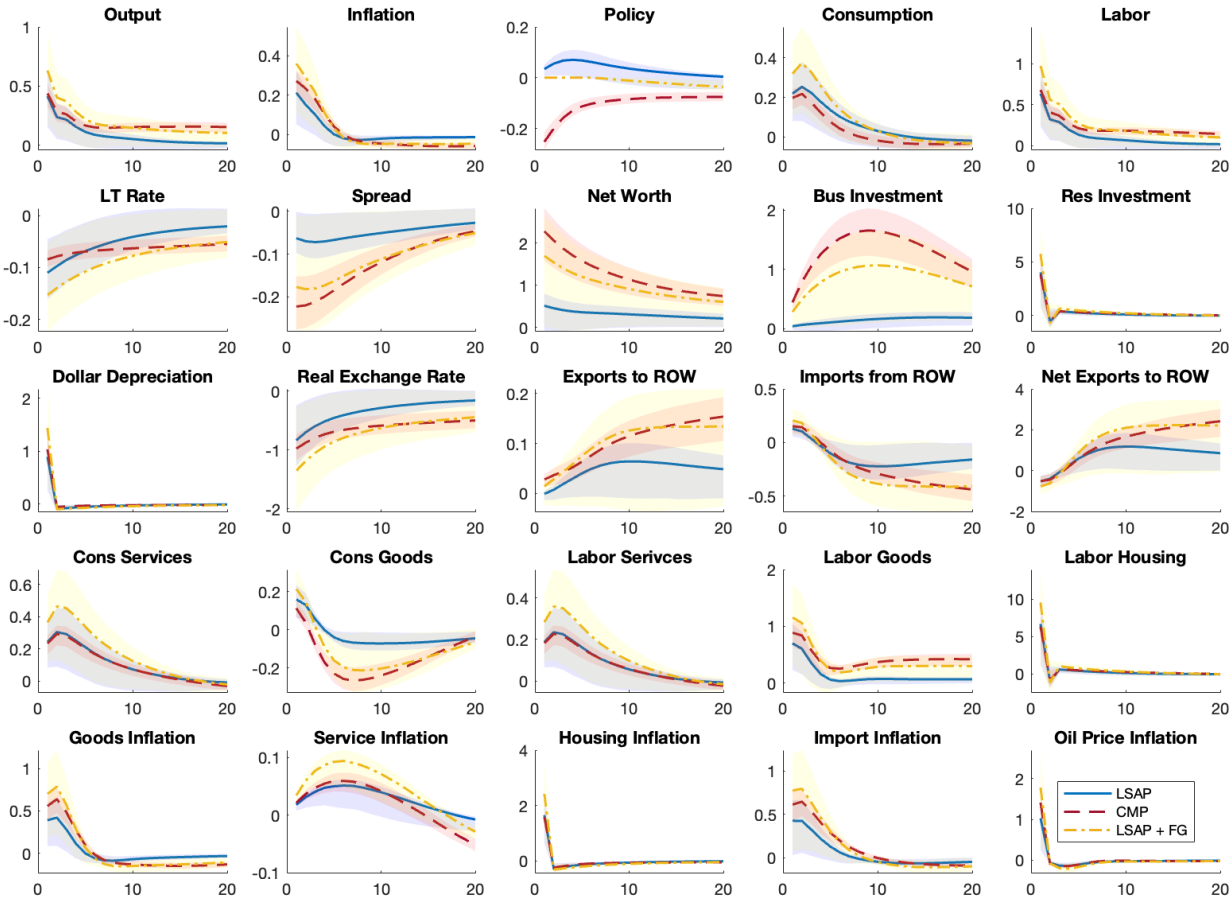
Responses to an LSAP shock are depicted by the solid blue line. This policy intervention is scaled for an LSAP shock that is equivalent to a long-term asset purchase of 1.5% of steady state annual GDP by the central bank at impact. The purchase is initially conducted at the model's steady state. We see 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. As expected, the long-term interest rate declines by about 15 basis points after the shock.[11] Business investment is marginally effected after the LSAP shock and goods prices rise by a smaller amount creating an increase in household goods consumption.

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 Great Recession 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 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. As a result the risk spread decline is not as great as a CMP shock but a bit greater than a regular LSAP 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.

[11] This impact on U.S. long-term yields is well within range of the estimates in the empirical literature (Hamilton and Wu (2012), Chen et al. (2012) and Sims and Wu (2021).

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.

4.3 LSAP Interaction with other Shocks

In this subsection, we will see that the macroeconomic impact of large-scale asset purchases with a commitment of stabilizing the policy rate will be different depending on what other shock might be happening additionally in the background. We will look at many of the shocks described and examined in section 4.1 and see that the macroeconomic impact of LSAPs on the economy and financial markets varies greatly depending if their is relatively more demand in a specific sector, corresponding price shocks in a specific sector or complementary fiscal transfer payments to the household. Examining these interaction effects between LSAP and other shocks will help us understand why unconventional monetary

policy after 2008 had such a different impact than similar policy conducted in 2020.

I examine these interactions by comparing the IRFs of a stand alone LSAP purchase and four quarter policy stabilization commitment to that of an economy that conducts that same LSAP purchase and four quarter policy stabilization commitment with a concurrent shock of interest after subtracting the IRFs of just the shock of interest. In the following plots the space between the solid blue lines (LSAP+) and dashed red lines (LSAP) represents how the concurrent additional shock alters the impact of LSAP on the macroeconomy and financial markets. If the two lines sit on top of each other we can conclude that the shock of interest has no interaction effect with the LSAP purchase. Consequently we are comparing the following dynamics:

IRF(LSAP with policy stabilization commitment and shock of interest)−IRF(shock of interest)

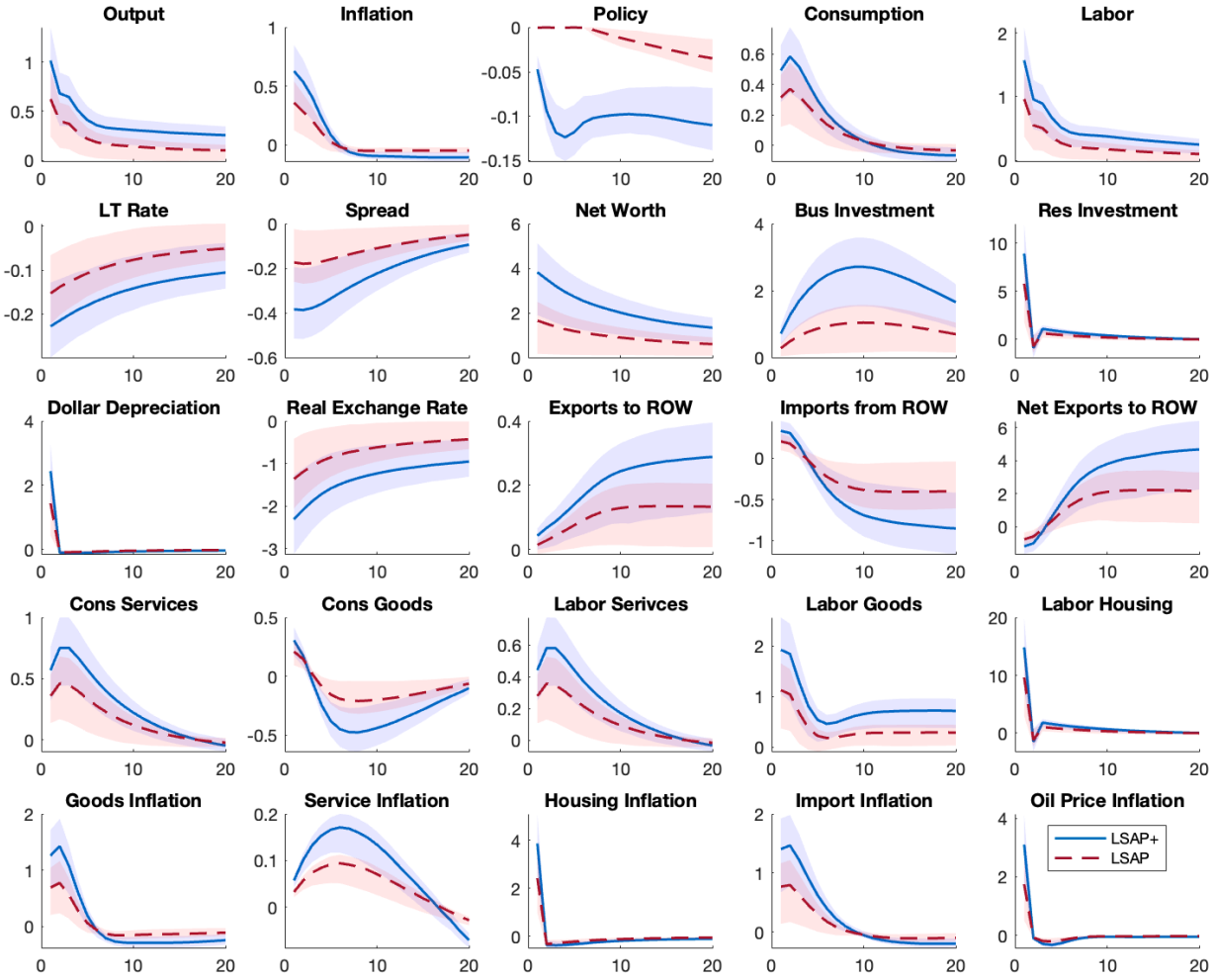
vs

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.

The result begins to taper when the elasticity of substitution of consumer services and consumer goods begins to rise. As the two become more substitutable consumers begin to substitute away from the higher priced sector dampening the overall effect of inflation and thus the need for strong anticipated monetary policy shocks to sustain the policy commitment. In addition, the result also tapers as the elasticity of substitution for foreign tradable goods increases as consumers and business can substitute domestic goods for foreign goods consequently lowering domestic demand and inflation.

Figure 6: Unconventional Monetary Policy with a Goods Demand Shock

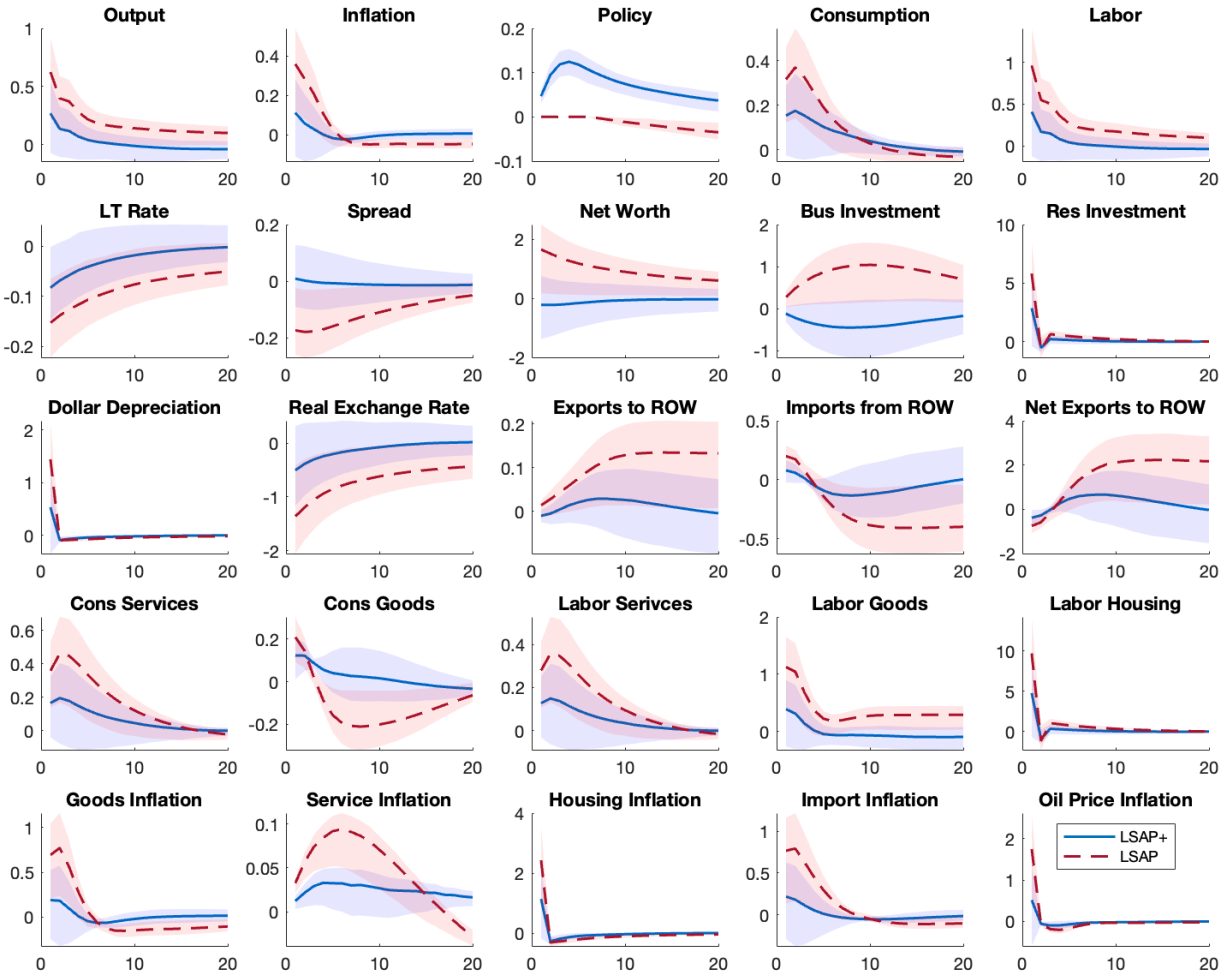


Notes: The dashed red line plots the response of an LSAP shock equivalent to a long-term asset purchase of 1.5% of steady state GDP by the central bank with a year's long commitment of keeping the policy rate unchanged. The solid blue line plots the impact of that same LSAP purchase and commitment with 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 their 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



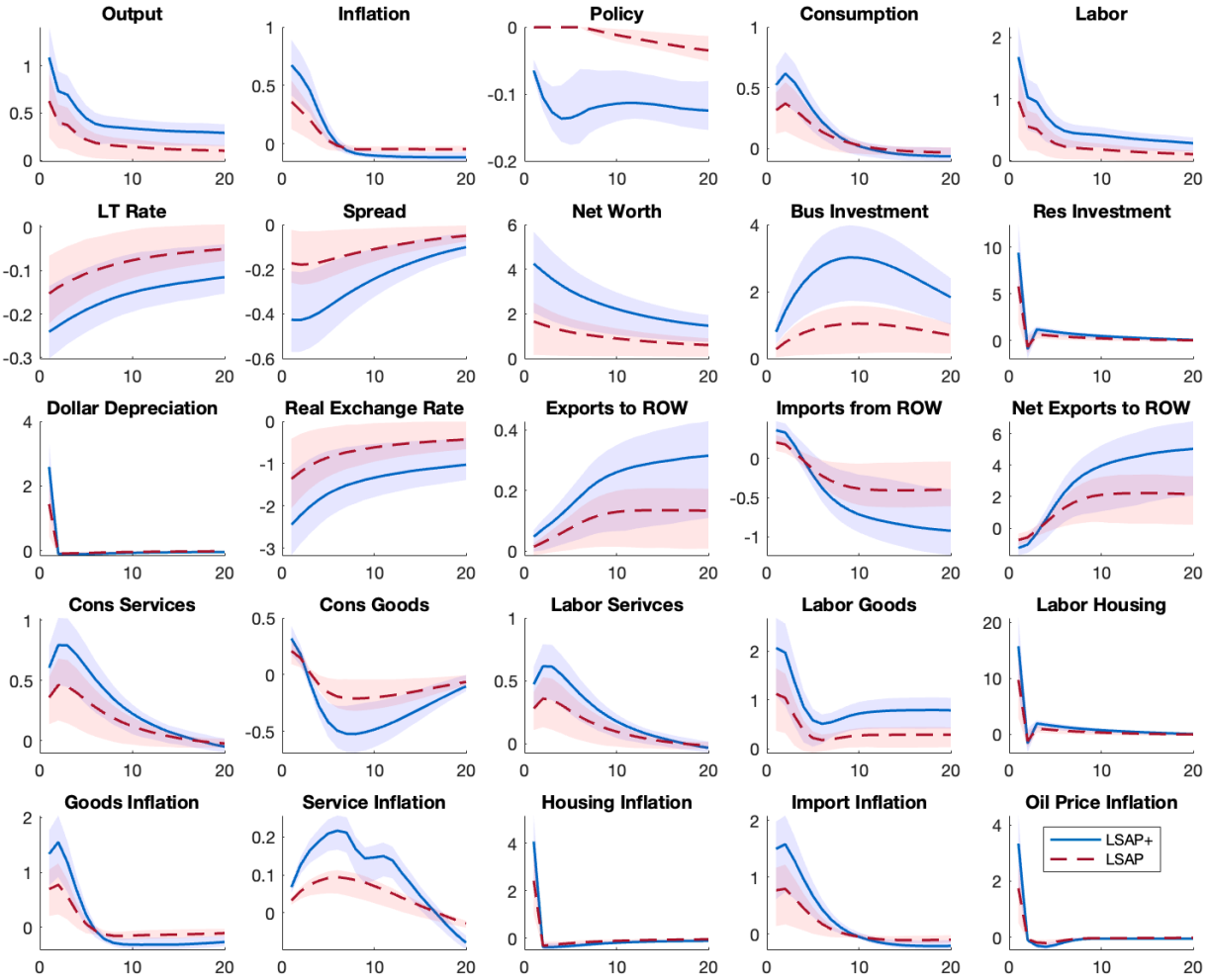
Notes: The dashed red line plots the response of an LSAP shock equivalent to a long-term asset purchase of 1.5% of steady state GDP by the central bank with a year's long commitment of keeping the policy rate unchanged. The solid blue line plots the impact of that same LSAP purchase and commitment with 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) than expansionary unconventional monetary policy becomes even more stimulative compared to just one sector seeing excess demand as can be seen in Figure A19. 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 demands between household consumption and savings

and relative demands between the goods and services sectors.

When comparing supply shocks (positive price shocks) in the sectors we see that unconventional monetary policy is boosted in an environment when their is positive price shock in the services sector and slightly dampened when their is a positive price shock in the goods sector. Figures 8 and A20 show the interactive dynamics of each.

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



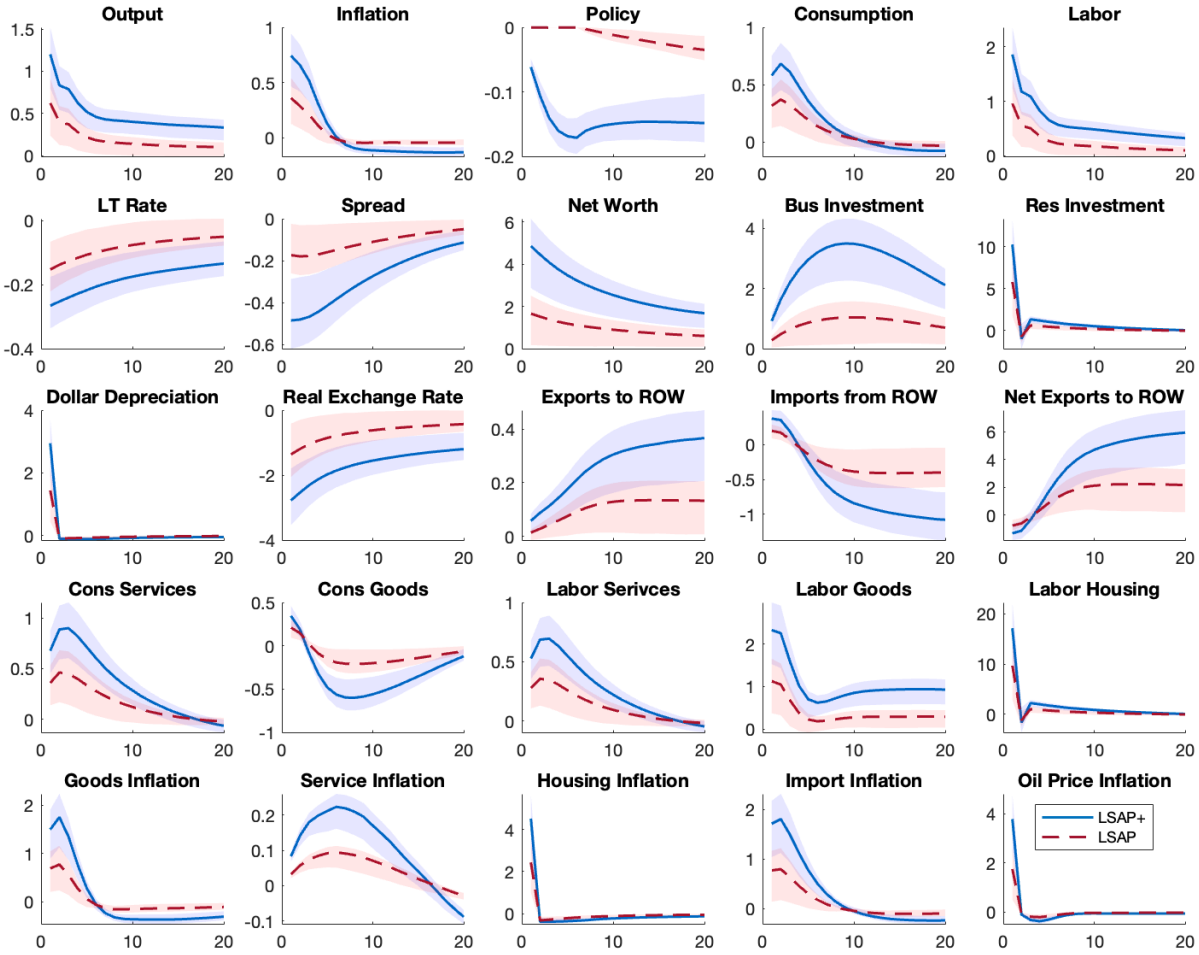
Notes: The dashed red line plots the response of an LSAP shock equivalent to a long-term asset purchase of 1.5% of steady state GDP by the central bank with a year's long commitment of keeping the policy rate unchanged. The solid blue line plots the impact of that same LSAP purchase and commitment with a concurrent shock to services prices after the dynamics of a stand-alone services price 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 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 shock in Figure A20, 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 is how unconventional monetary policy interacts with transfer payments in the form of lower taxes on the household. These tax transfer 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.

Figure 9: Unconventional Monetary Policy with a Transfer Payments



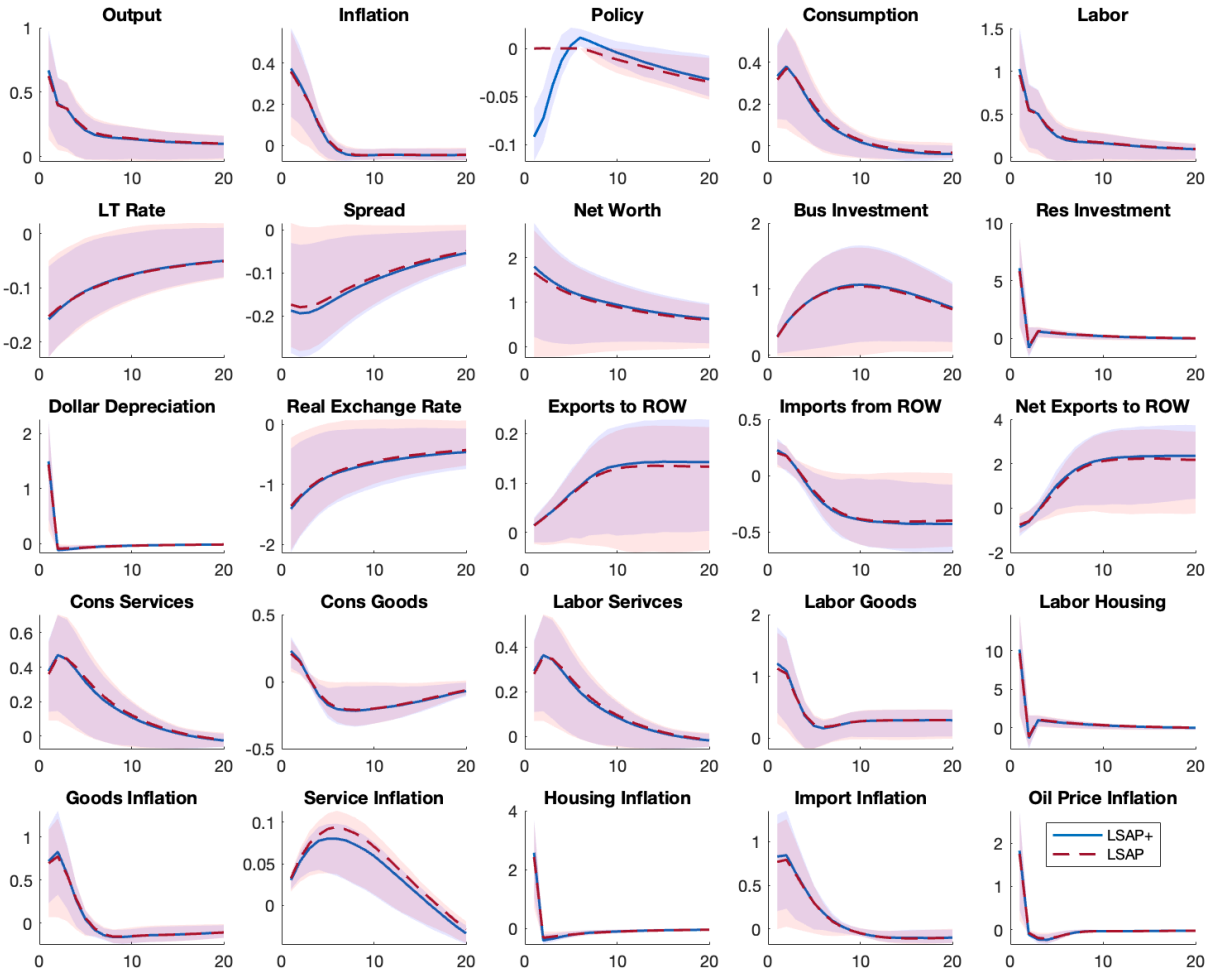
Notes: The dashed red line plots the response of an LSAP shock equivalent to a long-term asset purchase of 1.5% of steady state GDP by the central bank with a year's long commitment of keeping the policy rate unchanged. The solid blue line plots the impact of that same LSAP purchase and commitment with 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.

Finally,[12] in Figure 10 we highlight the lack of interaction effects of LSAP and and global supply chain shocks.[13] We can see that the blue line and regions lay entirely on top of the red line and regions. This suggests that LSAP with a policy commitment has the same effects whether there is a global supply chain disruption or not. This is because of the transitory or short-lived inflation (2-3 quarters) that occurs during the global supply chain disruption.

[12]In the appendix, Figure A21 also displays that a positive net worth shock (asset inflation) boosters the impact of expansionary unconventional monetary policy.

[13]A negative global supply chain shock is modeled as a concurrent positive domestic and ROW imports demand shock and positive domestic and ROW import price shocks. This creates an increase in global trade demand and a decrease in global trade supply.

Figure 10: Unconventional Monetary Policy with Global Supply Chain Pressure



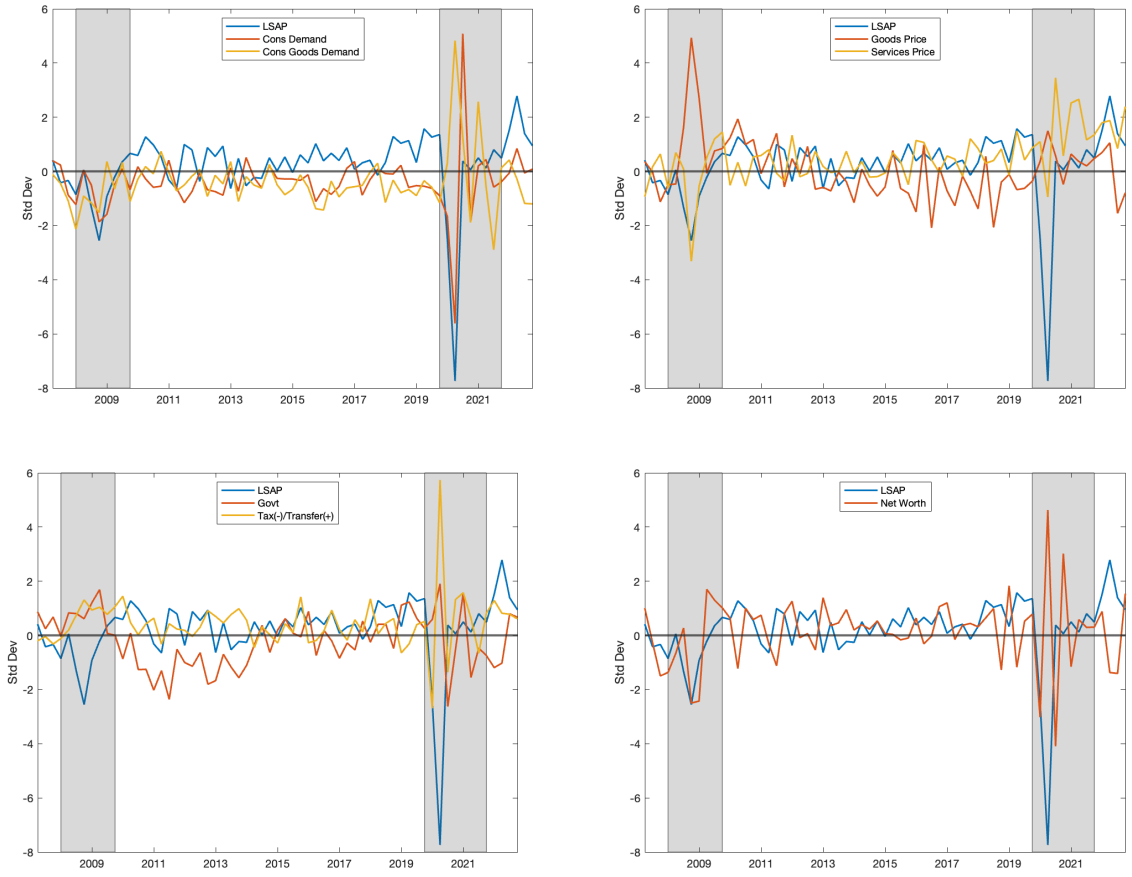
Notes: The dashed red line plots the response of an LSAP shock equivalent to a long-term asset purchase of 1.5% of steady state GDP by the central bank with a year's long commitment of keeping the policy rate unchanged. The solid blue line plots the impact of that same LSAP purchase and commitment with a concurrent negative global supply chain shock after the dynamics of a stand-alone global supply chain chock 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.

4.4 Understanding why the impact of Unconventional Monetary Policy was so different in 2020-21

Using the interaction effects discussed previously and Figure 11 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 (Quan-

titative Easing) correspond to the height of the 2008 global financial crisis and the 2020 COVID economy. However, what is different is the resulting shocks to demand, prices and transfer payments that occurred during each of these time periods.

Figure 11: 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.

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 shock is associated with a large positive price shock to goods and negative price shocks to services, while the 2020 LSAP shock corresponds with multiple positive service price shocks and more mild positive good price 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 shocks will all dampen the effect of unconventional monetary policy to macroeconomic variables, international trade and financial markets.

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.

5 Historical Decompositions

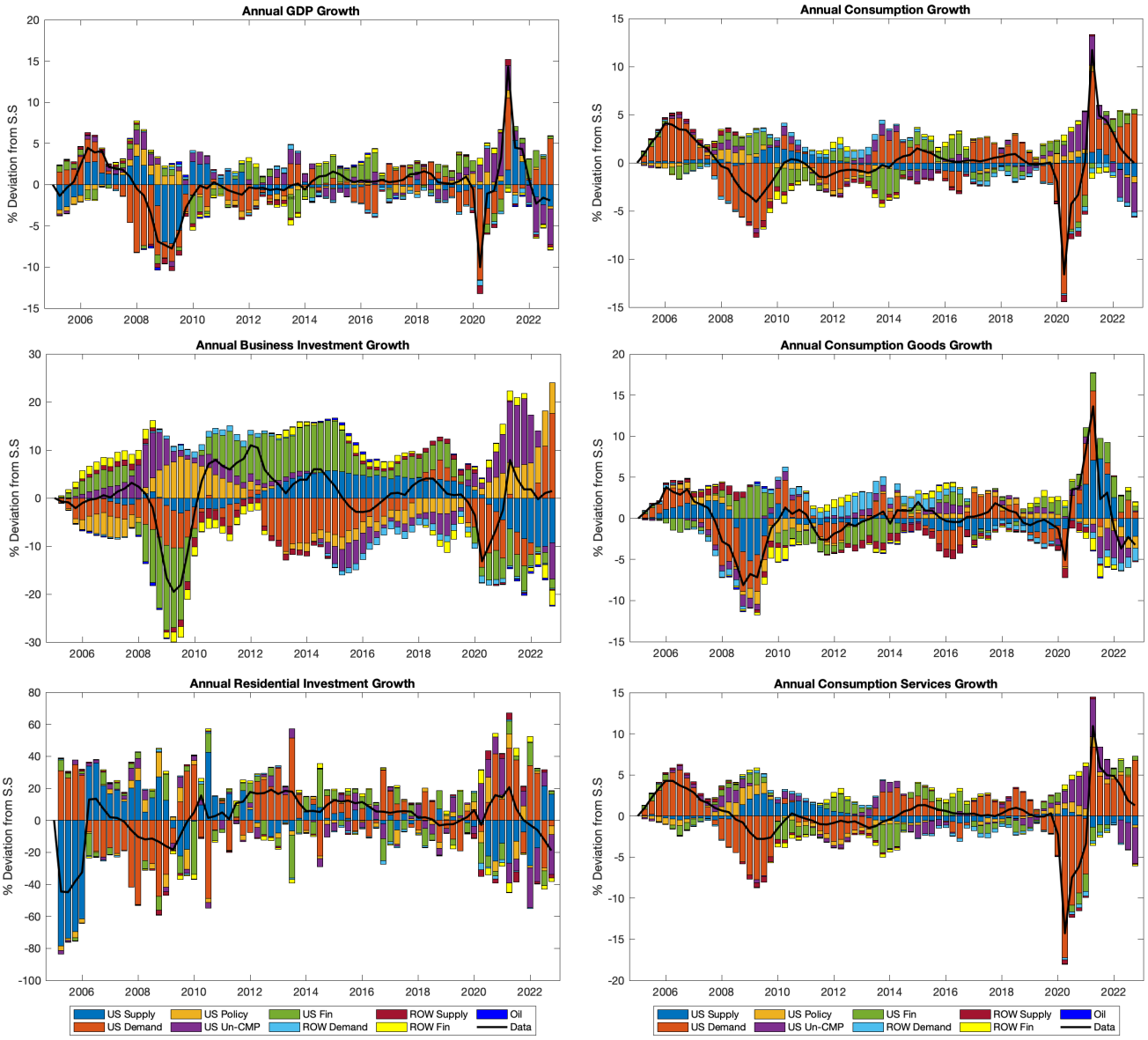
In the previous sections we have described the key mechanisms determining the policy transmission effects of the model and how they interact with other key shocks in the model. The model's framework enables us to identify the source of the past fluctuations for key financial and economic variables in terms of the exogenous processes. I use historical shock decompositions to describe how the model explains the evolution of real US variables, US inflation, and international variables 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 on 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, trade and oil.

The importance of each "type" of shock for the aforementioned variables is quantified in Figures 12-14. 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, 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 12 shows the decomposition of year over year growth in real GDP, consumption, goods consumption, services consumption, business investment and residential investment. It illustrates the dominant role demand shocks had in both the global financial crisis and the COVID economy. We see that US real activity is driven mostly by domestic shocks and the goods and housing sector dynamics is driven a bit more by supply shocks than the services sector. 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 12: Historical Decompositions - US Real Variables

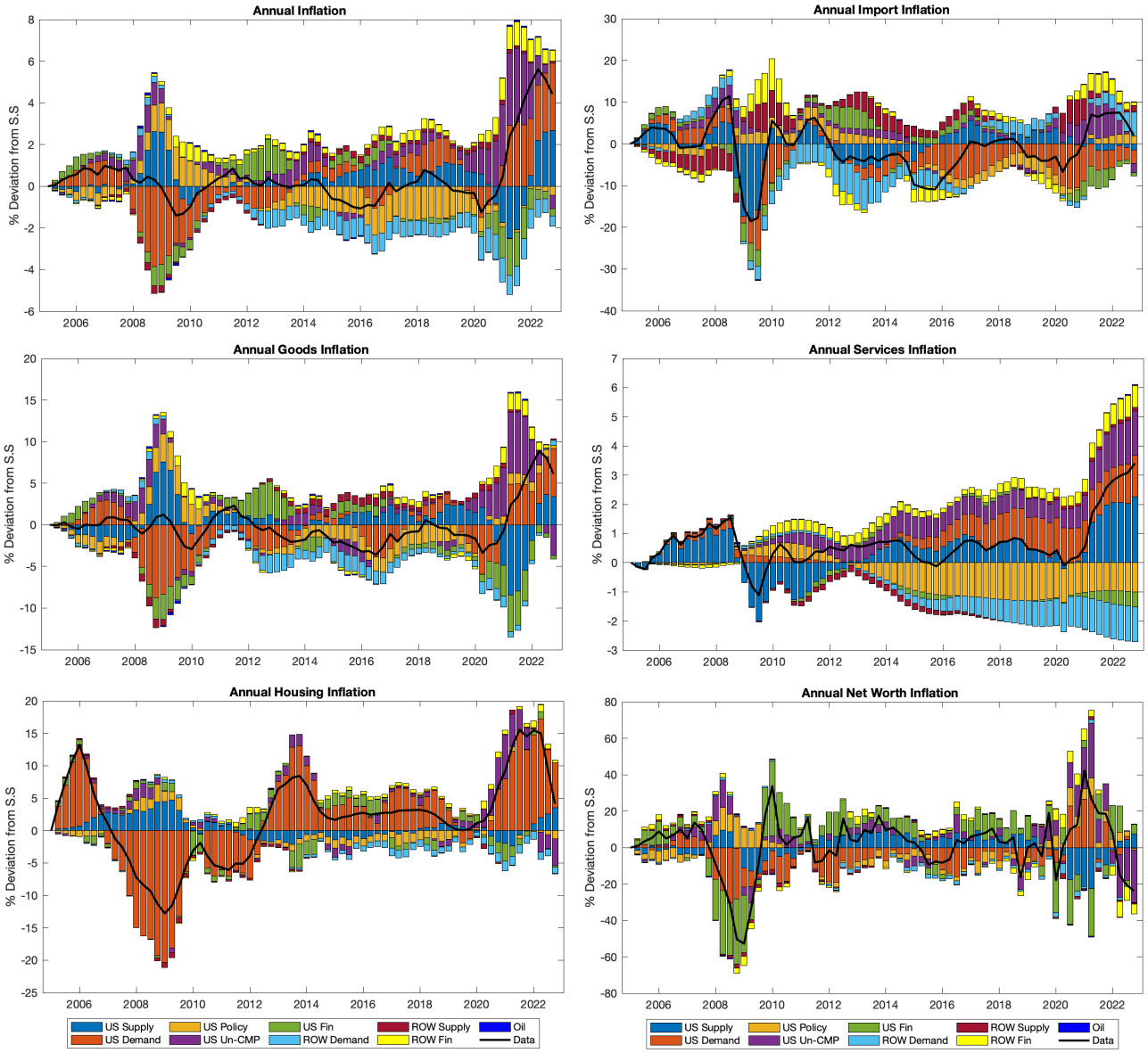


Notes: The figures plot the historical shock contributions for year over year (y-o-y) US GDP growth, Consumption growth, Consumption Goods growth, Consumption Services growth, Business Investment growth and Residential Investment growth. The shocks are grouped into nine categories. US Supply includes 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 13, 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 to significantly lead to an increase in 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 section 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 13: Historical Decompositions - US Inflation

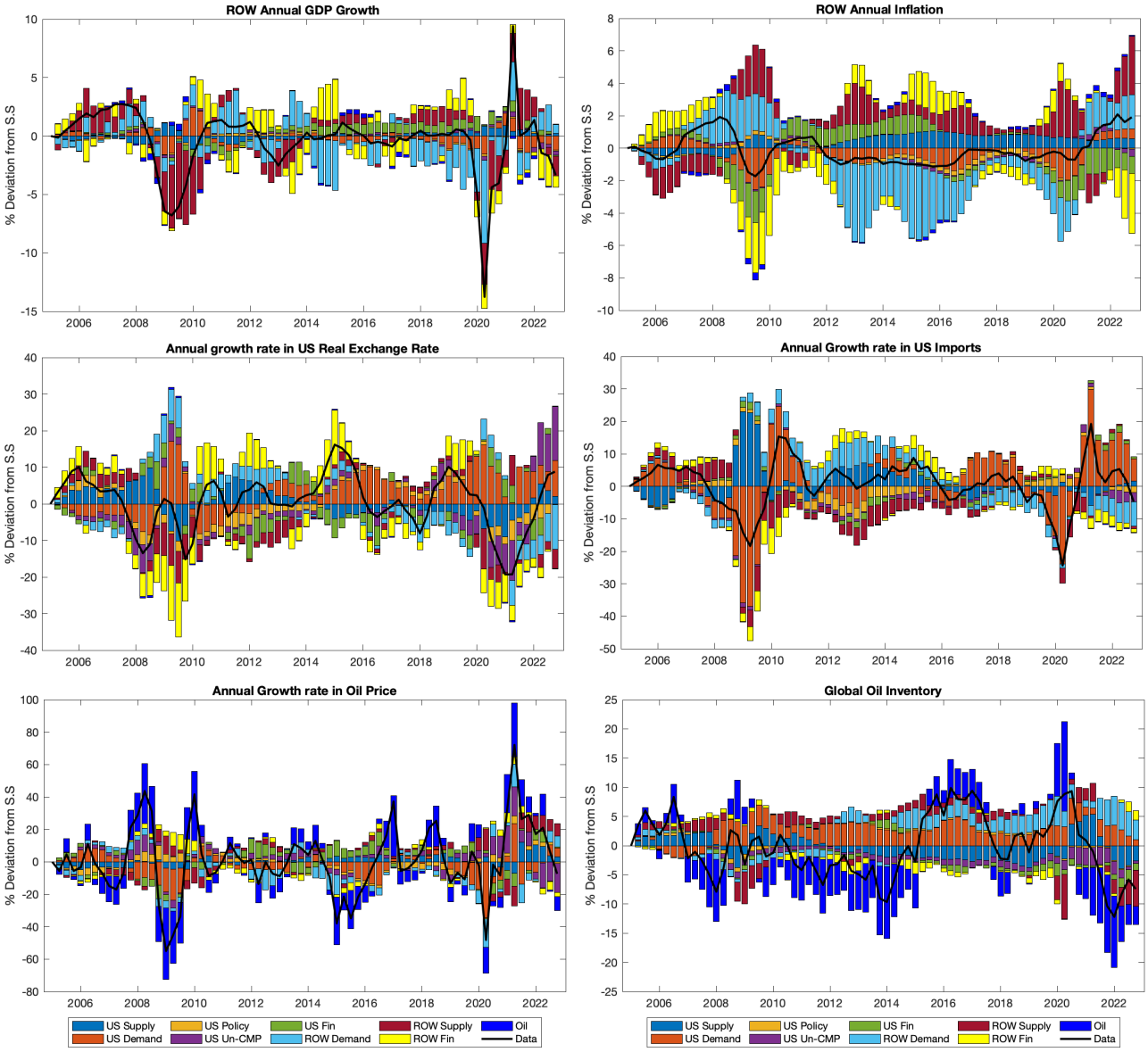


Notes: The figures plot the historical shock contributions for year over year (y-o-y) US Inflation, Import Inflation, Goods Inflation, Services Inflation, Housing Inflation and Net Worth Asset Inflation. The shocks are grouped into nine categories. US Supply includes US price and wage mark-up shocks 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.

Examining some international variables in Figure 14 we can see that consistent with Pasimeni (2022) and Cardani et al. (2023) the ROW was impacted by supply shocks to a greater extent than the US. The real exchange rate is significantly impacted in 2020 by expansionary monetary policy, yet there is little effect on real US imports as the growth in those are entirely driven by aggregate and relative sectoral demand shocks. This is consistent to the interactive effects of unconventional monetary policy discussed previously that saw a larger impact on exchanges rates and a more minimal impact on imports when policy was conduced during times of high overall consumption and goods demand.

Turning our attention to oil markets, we can see that most of the fluctuations of oil prices (oil inflation) and oil usage (inventory change) is driven by US and ROW demand. However, unconventional monetary policy that induced domestic demand and falls in the real US exchange rate created positive pressure on oil prices and more oil usage (lower inventory) throughout the 2020-2022 period. Once again by a much bigger margin than that of the 2008-2010 period. We see that Figures 12-14 are consistent with the results of sections 4.2-4.4 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 shocks in the services sector and in a world with large fiscal transfers.

Figure 14: Historical Decompositions - International



Notes: The figures plot the historical shock contributions for year over year (y-o-y) ROW GDP Growth, ROW Inflation, US real exchange rate growth, US Imports and Oil price Inflation as well as the above ground global oil inventory. 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.

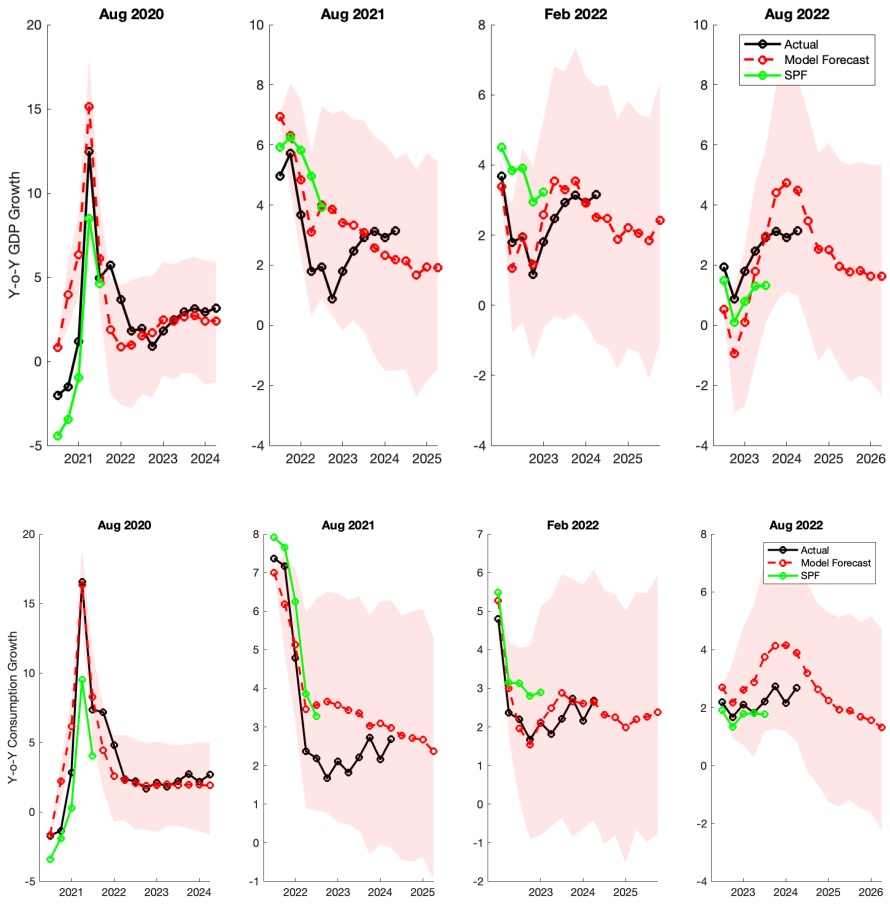
6 Forecasting

In this section I evaluate the simulated and forecasting ability of the model. I estimate the model using data up to 2020Q1 and I then compute pseudo out-of-sample forecasts around the COVID economy and its recovery. I introduce real-time forecasting using the assumption that the econometrician would use all real-time financial data (international and domestic) available for the current quarter. In addition the econometrician would also have the first monthly value for all data series in the model that are reported at a monthly frequency. The econometrician would then forecast the remaining two monthly observations for each partially reported data series using a simple AR(2) forecasting model to be able to generate the quarterly observation for all partially reported monthly frequency variables. For example, in generating the 2020Q3 forecasts the econometrician would know all non-financial data realizations up to and including 2020Q2, all financial data up to and including 2020Q3 and all monthly frequency variables up to 2020Q2 and the monthly observation for July 2020. They would then generate forecasts for August and September 2020 for a forecasted observation for 2020Q3.[14] In total each forecast is generated by 30,000 simulations, 1,000 draws from the posterior parameter distribution and each parameter draw is simulated using 30 draws of future structural shocks for 16 quarters.

Figures 15 and 16 show the forecasted paths of year over year US real GDP, consumption, consumption by sector and import growth for August 2020, August 2021, February 2022 and August 2022. For comparison, we plot the realized data in black and the Survey of Professional Forecasters (SPF) median estimate in green. We can see that the model in real time is better or on par with the SPF in predicting the bounce back in GDP and consumption starting in the third quarter of 2020, the deceleration of the recovery starting in the third quarter of 2021 and the stabilization of GDP and consumption growth starting in the first quarter of 2022.

[14] I do not reestimate the model parameters again, instead new data is introduced into the Kalman filter each period to generate the next sequence of model forecasts.

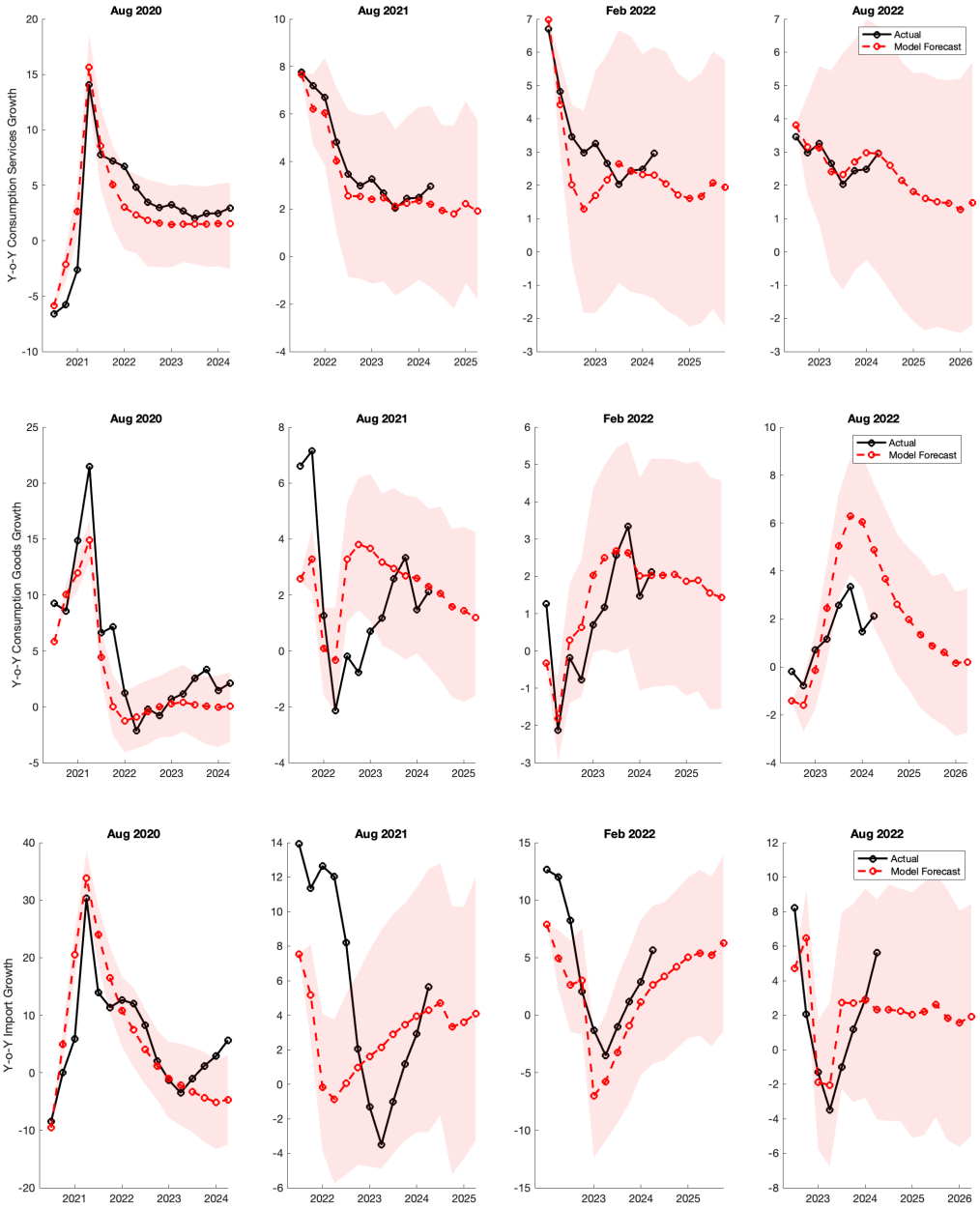
Figure 15: Model Forecasts - Real Activity



Notes: The figures plot the out-of-sample forecasts of year over year (y-o-y) growth in real GDP and consumption for August 2020, August 2021, February 2022 and August 2022. The red line plots the model forecast, the black line plots the realized data and the green line plots the Survey of Professional Forecasters median estimate. The shaded red area is the 90% confidence interval around the model forecast.

In Figure 16 we see how well the model captures the dynamics of services consumption throughout the examine time period. Further, the model is able to foresee the strong growth in goods throughout 2020 and 2021 and forecasts its decline starting in 2022. Goods consumption is over-forecasted for the 2023-2024 years which explains why GDP and total consumption is also over-forecasted for these time periods. We also see the accurate forecasts for imports that are generated in the model including the large growth rates in 2021 and 2022 and the decline in Imports starting in 2023.

Figure 16: Model Forecasts - Sectoral Forecasts

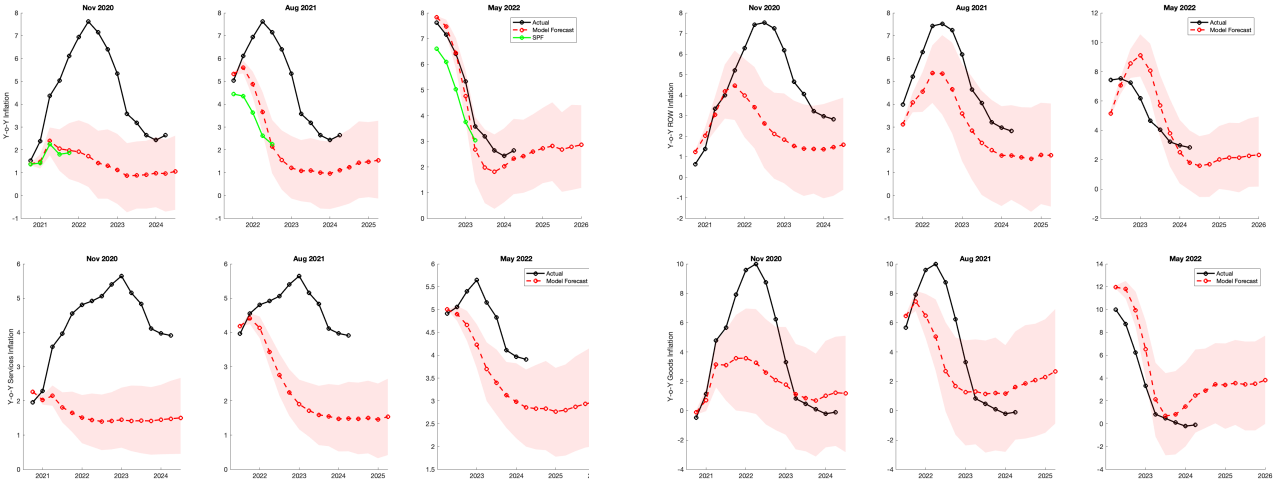


Notes: The figures plot the out-of-sample forecasts of year over year (y-o-y) growth in services consumption, goods consumption and Imports for August 2020, August 2021, February 2022 and August 2022. The red line plots the model forecast and the black line plots the realized data. The shaded red area is the 90% confidence interval around the model forecast.

In Figure 17 we turn our attention to forecasts of year over year inflation in the US, the ROW and US sectoral inflation. First, we see that the model does not do as good of job forecasting inflation as it did for real variables. It is not able to reproduce the build up and persistence in inflation for the US. It does however, do a better job for inflation in the ROW and forecasting the path of decline in inflation in the US after it peaked in 2022Q2.

Further, US inflation forecasts are initially on par with the SPF in 2020Q4 but are higher (more accurate) than the SPF in 2021Q3 and 2022Q2.

Figure 17: Model Forecasts - Inflation Forecasts



Notes: The figures plot the out-of-sample forecasts of year over year (y-o-y) growth in US Inflation, Services Inflation, Goods Inflation, US real Exchange Rate and the ROW Inflation for November 2020, August 2021 and May 2022. The red line plots the model forecast, the black line plots the realized data and the green line plots the Survey of Professional Forecasters median estimate. The shaded red area is the 90% confidence interval around the model forecast.

Although the model does not forecast an eventual increase in inflation to 8%, it would be wrong to say that the model does not foresee an increase in inflation as the economy reopens and recovers. In fact, in November 2020, the model predicted that high demand for goods would increase goods inflation to nearly 4% over the next year and half. Further, starting in August 2021, the model predicts that service inflation would remain at 4 to 5% over the next year. Again these totals undershoot the peak and underestimate the persistence of inflation in each sector but they are signaling inflation pressures in each even as the economy was below potential.

6.1 The importance of Sectors and Bond Portfolio Modeling

Throughout this paper we have seen the importance of the non-tradable service sector, the international bond portfolio and the interaction between the two in explaining the real and nominal changes to the economy that occurred in 2020 and the post Covid recovery. We can further highlight this point by examining the model forecasts when the service sector and the international bond portfolio (i.e. No LSAP policy) are "shut-off" in the baseline

model. Table 1 outlines what structural parameters are recalibrated to, what steady-states are recalculated and what observed data is no longer used in the estimation in order to eliminate the non-tradable service sector in the model, the international bond portfolio in the model, international trade in the model, the housing sector in the model and the oil sector in the model.[15]

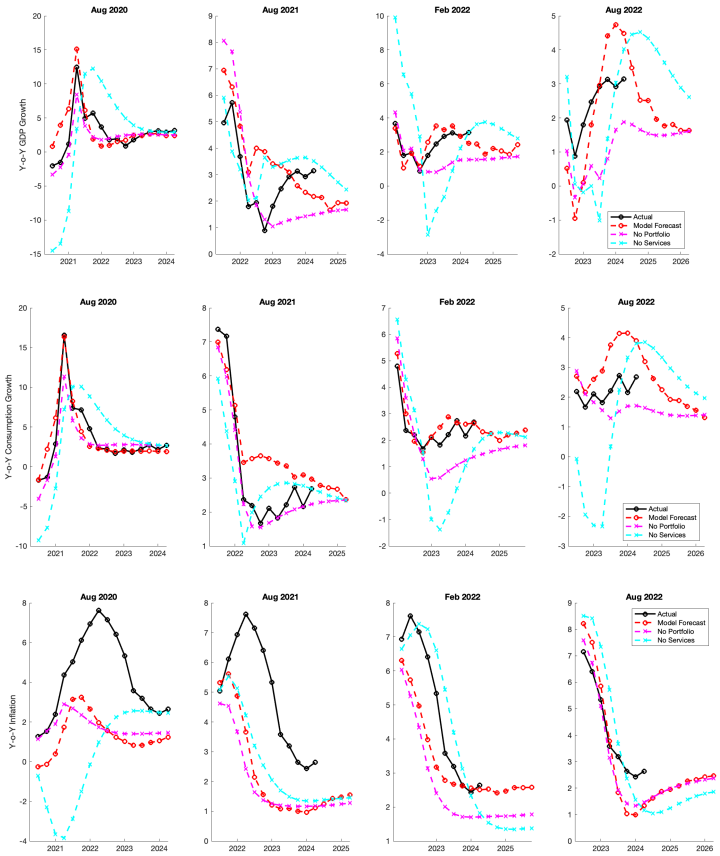
Table 1: Modeling Assumptions

Model	Changed Parameters	Dropped Data
No Services	$\gamma_{serv} = 0$, $\gamma^*_{serv} = 0$ $c_{serv}/y = 0$, $c^*_{serv}/y^* = 0$ $g_{goods} = 1$, $g^*_{goods} = 1$ $\alpha_K = .33$, $\alpha^*_K = .33$	US + ROW Consumption Goods Growth US + ROW Consumption Services Growth US + ROW Wage Inflation Services US Hours Growth in Goods Sector US + ROW Hours Growth in Services US + ROW Consumption Services Inflation Added ROW Aggregate Consumption Growth
No Int'l Portfolio	$\gamma_{a,s,L} = .999$, $\gamma^*_{a,s,L} = .999$ $\sigma_{\gamma_b} = 0$, $\sigma_{\gamma^*_b} = 0$ $\sigma_{\gamma_{a,s,L}} = 0$, $\sigma_{\gamma^*_{a,s,L}} = 0$	US + ROW Ten Year Rate US + ROW Public Debt to GDP All International Public Debt Owned Data
No Int'l Trade	$\gamma_{c,I} = .999$, $\gamma_{c,I} = .999$ $y^*_F/y = .001$, $y_F/y^* = .001$	US + ROW Import Inflation USD Depreciation US Import Growth All ROW Variables
No Housing	$\Delta_{hou} = .001$, $\Delta^*_{hou} = .001$ $\sigma_{a_{hou},hou_d w_{hou},hou} = 0$ $\sigma^*_{a_{hou},hou_d w_{hou},hou} = 0$	US + ROW Residential Inv US + ROW Housing Inflation US + ROW Hours Growth in Housing US + ROW Wage Inflation Housing
No Oil	$\alpha_{O,goods} = 0$, $\alpha^*_{O,goods} = 0$ $\alpha_{O,serv} = 0$, $\alpha^*_{O,serv} = 0$ $dom/y = 0$, $dom/y^* = 0$	Oil Price Inflation Oil Inventory OPEC+ Oil Supply Non-OPEC+ Oil Supply

Figure 18 plots the forecasted paths of year over year US real GDP, consumption, and inflation for August 2020, August 2021, February 2022 and August 2022 for the baseline model, the model with no service sector and the model with no international bond portfolio (i.e. no LSAP policy). We see that eliminating the service sector significantly worsens the forecast of GDP and consumption growth during 2020, as it predicts a much deeper and prolonged recession. Further, the serviceless model overstates the recovery in 2022 and predicts negative growth in 2023. On the inflation side the serviceless model predicts a deep deflation period in late 2020, it does however do the best job in predicting the behavior

[15]Some implicit model steady-states change when the following parameters/steady states are recalibrated for, therefore other non-listed steady state parameters are also resolved for.

Figure 18: Model Forecasts under different Modeling Assumptions



Notes: The figures plot the out-of-sample forecasts of year over year (y-o-y) growth in US GDP, Consumption and Inflation for August 2020, August 2021, February 2022 and August 2022. The red line plots the baseline model forecast, the black line plots the realized data, the light blue line plots the model forecasts under the assumption of no service sector and the purple line plots the model forecasts under the assumption of no international bond portfolios and central bank LSAPs.

of inflation starting in 2022. This is likely because the serviceless model has less sticky aggregate prices and thus predicts a large demand pull inflation episode, overshooting on real growth but increasing the overall inflation forecast with it.

Examining the model with no international portfolio and no LSAP policy we see similar results to the baseline model, however a slightly lower inflation forecast throughout the examined period. Further, the no international portfolio model under forecasts actual growth in real GDP and consumption that occurred in late 2022 to 2024.

Table 2 examines the forecast accuracy of each of the models listed in Table 1 since 2010 using a once a year re-estimate of each model. We see that the baseline model consistently has the lowest root mean square errors (RMSEs) for US GDP, inflation and imports compared to the other five nested models. This suggests that the importance of a multi-sector,

modeled international unconventional monetary policy and open-economy model is critical in capturing the dynamics of the economy in the pre and post COVID eras.

Table 2: Relative RMSE's under different Modeling Assumptions

	Annual GDP Growth			Annual Inflation			Annual US Imports		
Model	h=2	h=4	h=8	h=2	h=4	h=8	h=2	h=4	h=8
No Services	**1.24**	**1.58**	**1.07**	**1.61**	**1.51**	1.04	1.00	**1.08**	**1.07**
No Int'l Portfolio	**1.11**	0.92	0.84	**1.13**	**1.26**	**1.14**	**1.07**	**1.47**	**1.38**
No Int'l Trade	1.06	1.03	0.99	1.03	**1.20**	**1.23**	-	-	-
No Housing	**1.09**	**1.22**	1.06	1.06	**1.08**	1.01	0.99	1.00	1.03
No Oil	0.94	1.02	1.04	**1.15**	**1.15**	1.03	1.00	0.99	1.04

Notes: The table shows the ratios of the RMSE from a given model in comparison to the baseline model forecasts for a given variable. Values above one indicate that forecasts from the model are on average less accurate than the baseline model. Bold entries under the columns denote the 5% significance level of the Diebold-Mariano test that the baseline model's forecasts' are more accurate while red entries indicate the model's forecast is more accurate than the baseline model at the 5% significance level.

We can further see the importance of including multi-sectors, international trade and international portfolios into the model by examining Table 3. 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.

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 the is no international trade in the model inflation is much more volatile then 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

Table 3: 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	2.19	2.21	2.38	2.2
std$(C_t - C_{t-4})$	2.35	2.14	2.66	2.03	2.18
std$(C_{goods,t} - C_{goods,t-4})$	3.23	2.13	2.66	1.98	2.10
std$(C_{serv,t} - C_{serv,t-4})$	2.56	2.77	-	2.55	2.48
std$(Y_{F,t} - Y_{F,t-4})$	7.05	6.10	3.92	-	3.90
std$(I_t - I_{t-4})$	5.99	6.31	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	1.01	-	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	0.39	-	0.22	0.40
Corr(π, π_{goods})	0.80	0.69	0.99	0.67	0.67
Corr(π, π_{serv})	0.85	0.88	-	0.89	0.89
Corr$(\pi_{goods}, \pi_{serv})$	0.60	0.33	-	0.28	0.25

to replicate the moments seen in the data for sectoral consumption, sectoral inflation and international trade.

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.

Lastly, I evaluate the forecast accuracy of the model compared to the Survey of Professional Forecasters (SPF) and other nested DSGE model set-ups. I find that the developed model of the paper is best in capturing the features of the COVID recession and its recovery while preserving the model dynamics prior to 2020. Although the baseline model is unable to capture the magnitude of peak inflation seen in 2022, it does predict a higher value than the SPF throughout this period and captures the dynamics associated with the US exchange rate, international trade and sectoral consumption. 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

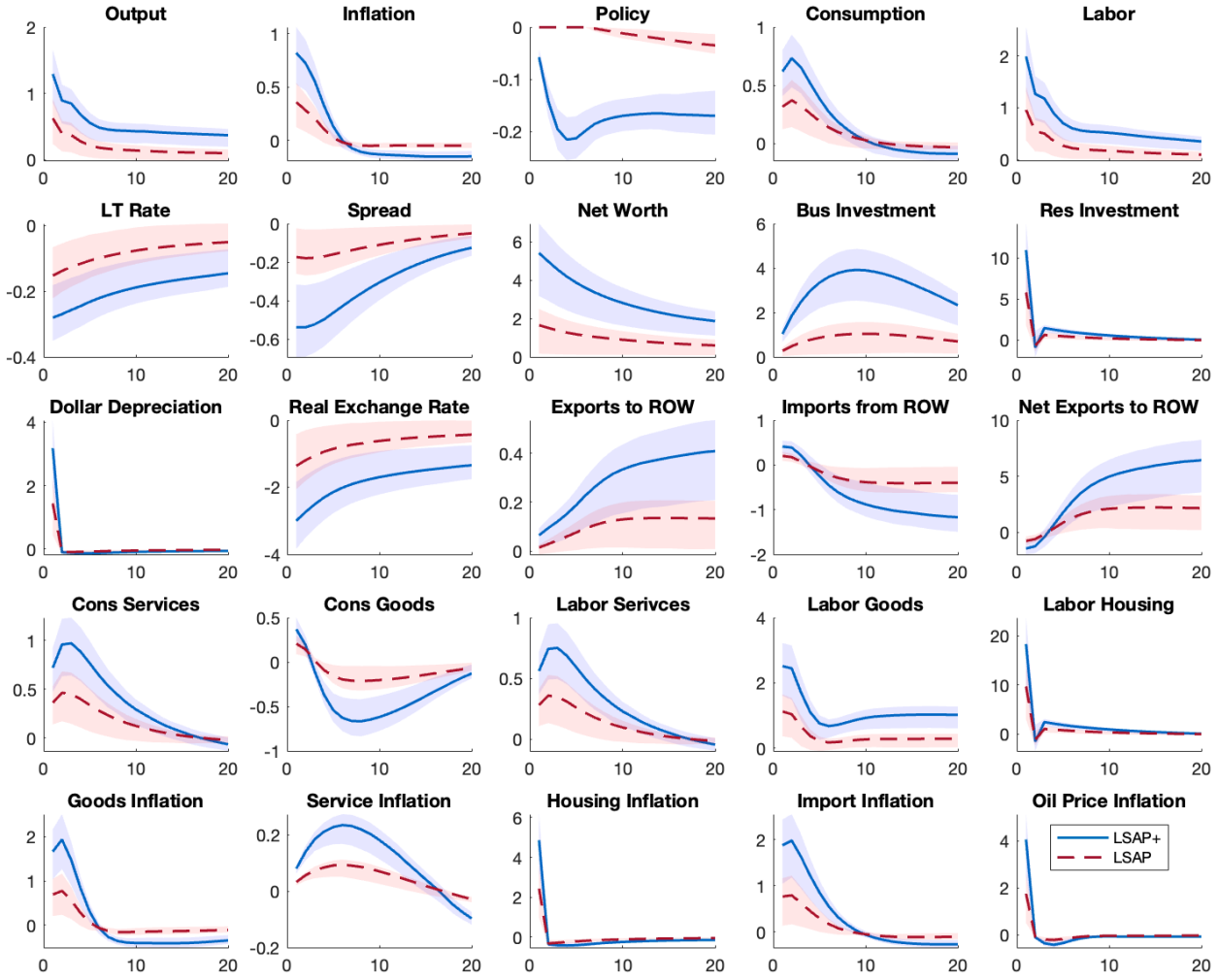
Table A4: Prior and Posterior Estimates - Structural Parameters

			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
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 A5: Prior and Posterior Estimates - Exogenous Shock Parameters

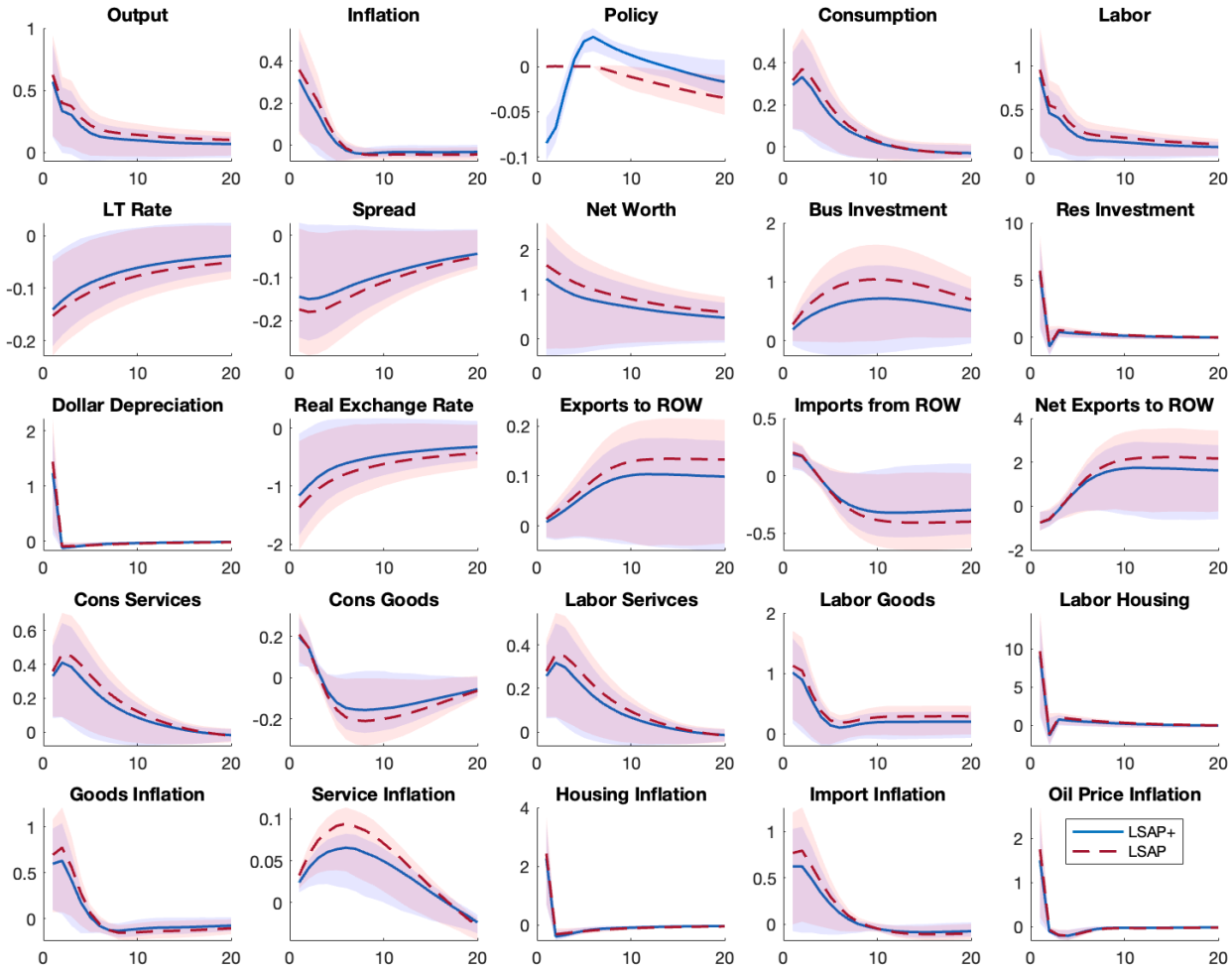
Parameter		Prior	U.S. Posterior Mean	U.S. Posterior 5%	U.S. Posterior 95%	ROW Posterior Mean	ROW Posterior 5%	ROW Posterior 95%
Shock Standard Deviations (x100)								
Wage Goods Shock	$\sigma_{w,goods}$	$IG(0.5, 0.4)$	0.30	0.26	0.34	0.68	0.60	0.77
Wage Services Shock	$\sigma_{w,serv}$	$IG(0.5, 0.4)$	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 Price Shock	σ_H	$IG(0.5, 0.4)$	1.12	0.96	1.30	1.19	1.01	1.39
Housing Price Shock	σ_{hou}	$IG(0.5, 0.4)$	7.67	6.12	9.35	4.64	3.55	5.78
Services Price Shock	σ_{serv}	$IG(0.5, 0.4)$	0.25	0.21	0.28	0.80	0.68	0.95
Import Price 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 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 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	-	-	-

Figure A19: Unconventional Monetary Policy with a Consumption Demand Shock



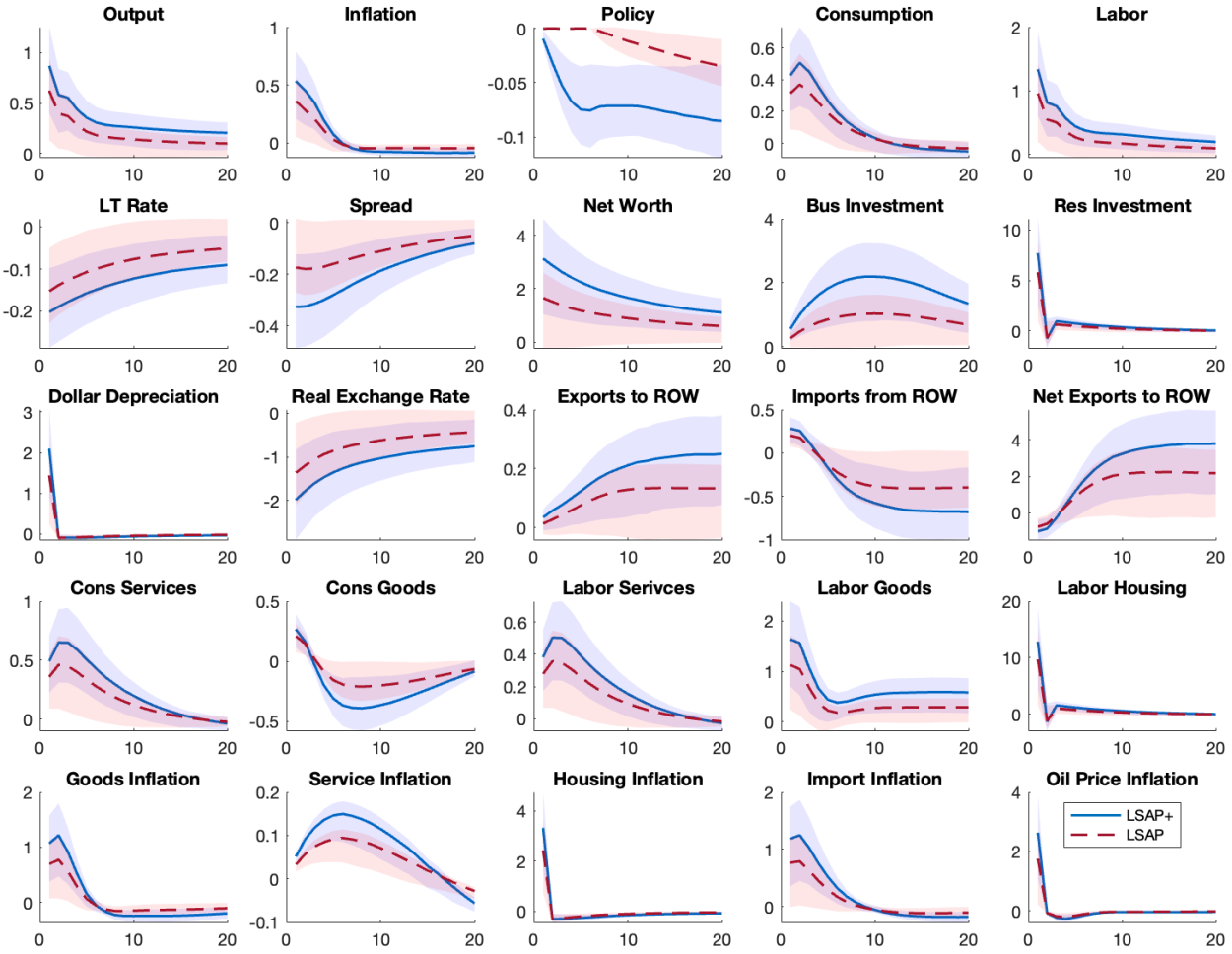
Notes: The dashed red line plots the response of an LSAP shock equivalent to a long-term asset purchase of 1.5% of steady state GDP by the central bank with a year's long commitment of keeping the policy rate unchanged. The solid blue line plots the impact of that same LSAP purchase and commitment with 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 A20: Unconventional Monetary Policy with a Goods Supply Price 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 price 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 A21: 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.