EUROPEAN CENTRAL BANK

EUROSYSTEM

Working Paper Series

Jagjit S. Chadha, Luisa Corrado, Jack Meaning, Tobias Schuler

Monetary and fiscal complementarity in the Covid-19 pandemic

No 2588 / September 2021

Abstract

In response to the coronavirus (Covid-19) pandemic, there has been a complementary approach to monetary and fiscal policy in the United States with the Federal Reserve System purchasing extraordinary quantities of securities and the government running a deficit of some 17% of projected GDP. The Federal Reserve pushed the discount rate close to zero and stabilised financial markets with emergency liquidity provided through a new open-ended long-term asset purchase programme. To capture the interventions, we develop a model in which the central bank uses reserves to buy much of the huge issuance of government bonds and this offsets the impact of shutdowns and lockdowns in the real economy. We show that these actions reduced lending costs and amplified the impact of supportive fiscal policies. We then run a counterfactual analysis which suggests that if the Federal Reserve had not intervened to such a degree, the economy may have experienced a significantly deeper contraction as a result from the Covid-19 pandemic.

Non-technical summary

The 2020 pandemic had the features of a perfect storm: a supply (shutdown) and demand shock (lockdown), which halted the functioning of the global economy for several months. We examine the critical role of monetary policy in offsetting these shocks and in particular in providing support for the fiscal policy interventions. We examine and calibrate the responses of the Federal Reserve in the United States, but the results can be generally interpreted as reflecting the supportive policies adopted by major central banks.

In response to the coronavirus (Covid-19) pandemic, there has been a complementary approach to monetary and fiscal policy in the United States with the Federal Reserve System purchasing extraordinary quantities of securities and the government running a deficit of some 17% of projected GDP. The Federal Reserve pushed the discount rate close to zero and stabilised financial markets with emergency liquidity, which had been a key instrument innovation during the financial crisis. In March 2020 the Federal Reserve initially implemented emergency refinancing by cutting its discount rate close to zero and by setting a USD 700 billion limit for asset purchases.

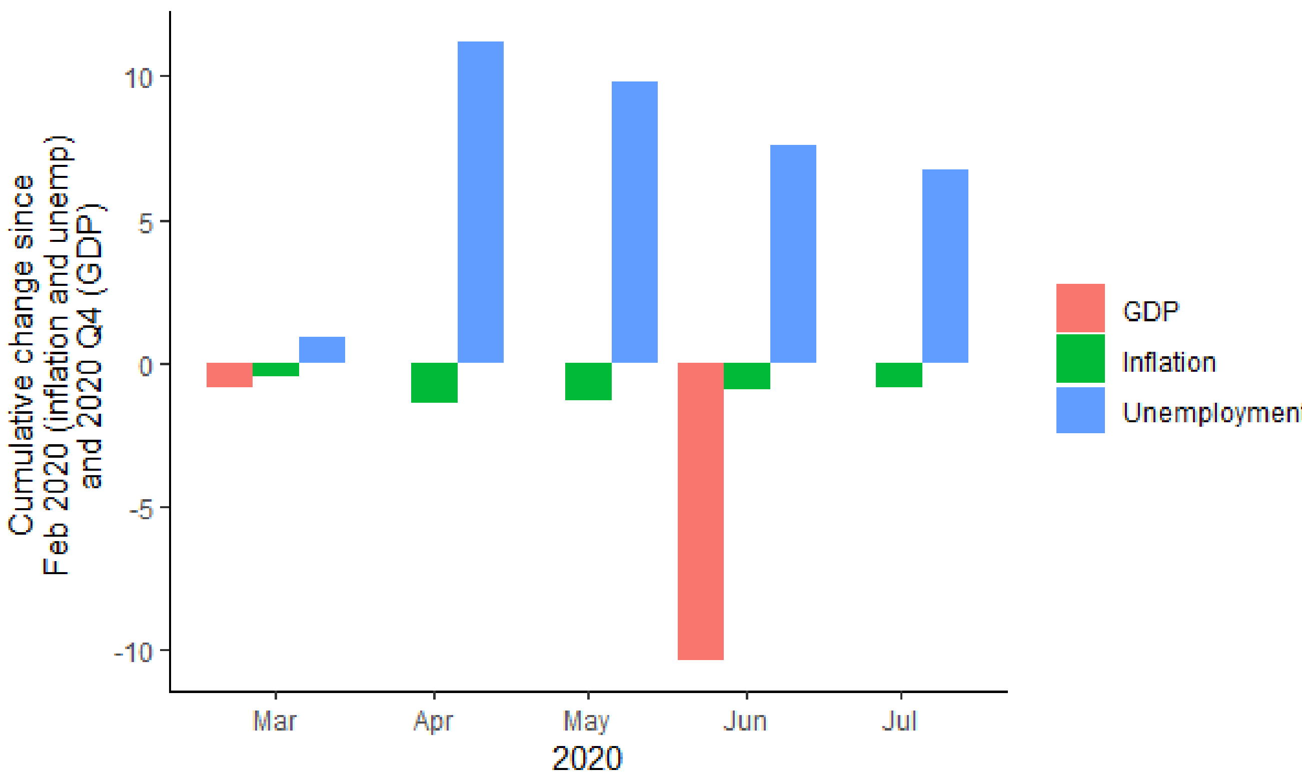
We are able to match stylised facts in the United States by implementing a shock to the velocity of money and to labour supply. To capture the interventions, we develop a model in which the central bank uses reserves to buy much of the huge issuance of government bonds and this offsets the impact of shutdowns and lockdowns in the real economy. We show that these actions reduced lending costs and amplified the impact of supportive fiscal policies.

We demonstate how a combined fiscal-monetary response helped avoid turning the Covid-19 crisis into an economic recession of even greater magnitude and severity in a counterfactual analysis. Our calibrated model shows that if the Federal Reserve had not intervened, output would have fallen by more than 10% more on impact and in the following quarter. Real wages would be down by more than 15% more and unemployment up by more than 20%. Wages would be 20% lower than with QE. As a result inflation would have fallen even further. Hence, we find that prompt, combined fiscal-monetary interventions mitigated the impact of the pandemic shocks and helped to establish a more rapid recovery to pre-crisis levels of activity.

1 Introduction

The economic consequences of the Covid-19 pandemic have been dramatic. In the United States, real GDP fell by more than 10% in the first six months of 2020 when compared with the final quarter of 2019 (Figure 1). The unemployment rate soared in April when restrictions on movements were first introduced rising by 11.2 percentage points when compared to February 2020 and almost hitting 15%. The initial impact softened somewhat. Unemployment stood at 8.4% in August 2020 and subsequently fell to 6% in March 2021. The rate of inflation, measured by the personal consumption expenditure price index, fell from 1.8% in February to 0.5% in April and May 2020, but picked up to 1% in July 2020 and was 1.6% in March 2021. We contend that a complementary monetary and fiscal strategy limited the impact of Covid-19 on the US economy.

Figure 1: US macro variables



Source: Federal Reserve Bank of St Louis (FRED).

To capture the salient features of the crisis, we augment the macroeconomic model with the banking system of Chadha, Corrado, Meaning and Schuler (2020) to understand the impact of the lockdown (as a negative velocity shock), the shutdown (as a negative labour supply shock) and the fiscal response (as a positive support to aggregate demand financed by the issuance of government bonds) in conjunction with the supportive monetary policy response of the Federal Reserve System, which we show amplified the stabilising force of discretionary fiscal policy (see

Bartsch et al, 2020). In this model, the central bank uses reserves to buy government bonds with reserves to offset the shutdown and lockdown shocks in the real economy. We show that the provision of reserves stabilised the value of collateral and amplified the impact of supportive fiscal policies. The responses of monetary aggregates to the pandemic shocks, and the role they have played under the influence of monetary and fiscal policies - in the subsequent economic path provide a key feature for the calibration and aid our understanding of the economic and policy mechanisms at work during the pandemic. Our calibrated model suggests that the fall in output in the first stage of the pandemic might have been as much as twice as large, with a significant deflation, loss of employment and falls in asset prices, if such extensive fiscal and monetary policies had not been implemented (Bullard, 2020).

1.1 Monetary-fiscal interactions in response to the Covid-19 crisis

To limit the economic impact of lockdown and shutdown, the Federal Government, as many governments around the world, ran unprecedented peacetime fiscal deficits. A key feature of government debt management has been massive purchase of government securities by the Federal Reserve. The purchases began in March 2020 after market liquidity became impaired, and an initial motivation was to restore market function.

In the United States, an avalanche of debt issuance in March and April overwhelmed the capacity of primary dealers in government securities. Foreign investors also sold USD 498 billion of Treasury notes and bonds in those two months, compared with average monthly sales of USD 6 billion over the year to February 2020.[1] The Federal Open Market Committee (FOMC) promptly announced that it would purchase US Treasury securities "in the amounts needed to support smooth market functioning and effective transmission of monetary policy to broader financial conditions and the economy."[2] We interpret this steps as the Federal Reserve providing a complementary monetary policy response to support the fiscal policy response for the impact of Covid-19.

Accordingly in the United States, the Federal Reserve bought USD 1.4 trillion (gross) of Treasury coupon securities by the end of April 2020.[3] The purchase rate decreased during April and May, and by the beginning of 2021 was about USD 80 billion a month, plus USD 40 billion of mortgage-backed securities, in all about 7% of GDP (Figure 2).

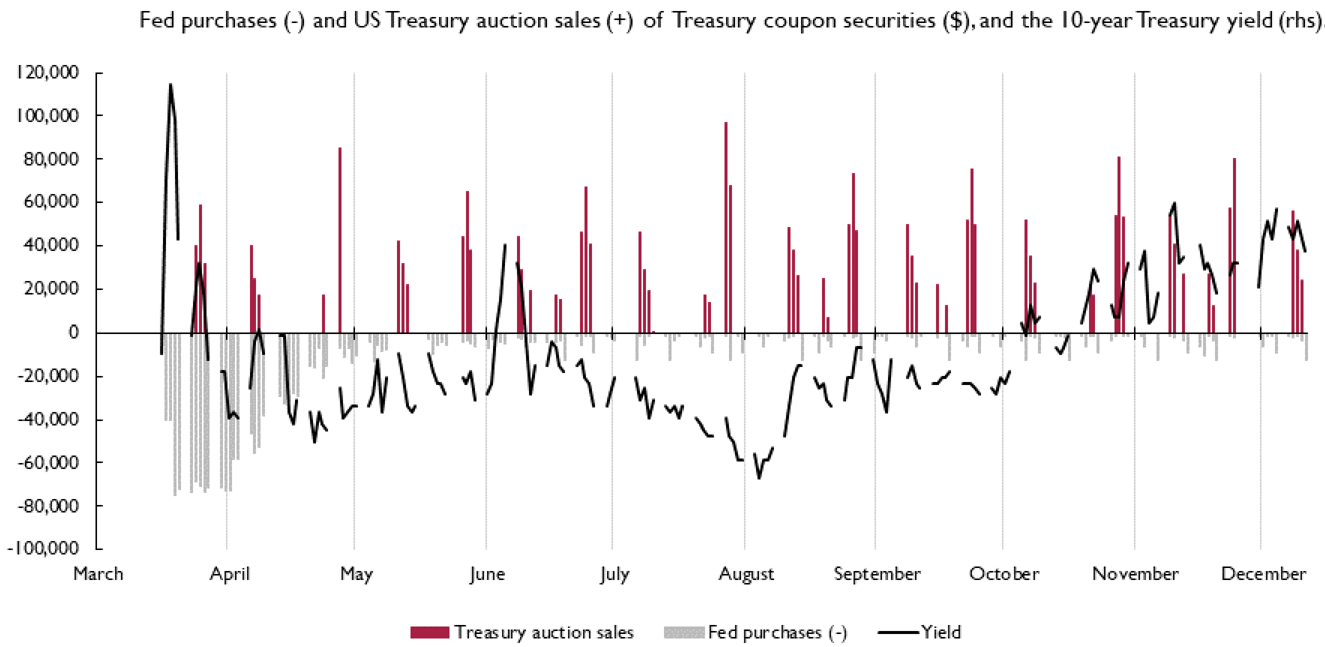
The Federal Reserve has undertaken to maintain this purchase rate "until substantial further

[1]See U.S. Treasury (2020).

[2]Federal Reserve (2020a).

[3]In response to the Covid-19 pandemic, the Federal Reserve resumed purchasing extraordinary quantities of securities, which had been a key instrument innovation during the financial crisis of 2008-09. In March 2020 the Federal Reserve initially implemented emergency refinancing by cutting its discount rate close to zero and by setting a USD 700 billion limit for asset purchases. After stabilising the market with emergency liquidity the Federal Reserve announced a new stream of open-ended long-term asset purchasing program in amounts judged sufficient to support the smooth functioning of markets in response to the pandemic shocks.

Figure 2: Fed purchases and Treasury auction sales



Source: Allen (2021)

progress has been made toward the [Federal Open Market] Committee's maximum employment and price stability goals".[4][5]

Long-term bond yields fell after the March 2020 announcement and continued to fall until August, after which they reversed much of the earlier fall (Figure 2). The reversal was probably a reaction to the Federal Reserve's revised statement on 27 August of its longer-run inflation goals, in which the policy objective was an aim for inflation "that averages 2 per cent over time", and that it would compensate for periods of persistently below target inflation by aiming for

[4]Federal Reserve (2020b).

[5]The expansion of narrow money directly accounted for by the Federal Reserve's QE purchases can be thought of as a "supply-driven" increase in reserves, with the quantity determined by the Federal Reserve. However, there has also been an endogenous increase in narrow money that has been more "demand-driven". As part of its response to the pandemic, the Federal Reserve also announced other policy moves, such as a lending program for businesses and facilities aimed to help markets for commercial paper, corporate debt and municipal bonds. Some of these schemes, such as the Primary Dealer Credit Facility, the Money Market Mutual Fund Liquidity Facility and the Commercial Paper Funding Facility are new iterations of programmes that were utilised in the global financial crisis of 2008-09. Others, such as the Paycheck Protection Program Liquidity Facility, are novel developments. The take up of these facilities has been an order of magnitude smaller than the expansion of reserves created by the Fed's asset purchases. Drawings on the Primary Dealer Credit Facility, the Money Market Mutual Fund Liquidity Facility, the Commercial Paper Funding Facility II and other corporate credit facilities at the Federal Reserve have totalled around USD 87 billion over the same period. Drawings on the Paycheck Protection Program Liquidity Facility increased reserves by a further USD 49 billion. It is perhaps not surprising that banks have not had a great need to draw on these funds to get liquidity when the assets purchase programme has meant that their balance sheets are already flush with liquid reserves and has dramatically increased the supply of deposits they can draw on for funding.

moderately above-target inflation for a period. It might also have reflected somewhat the slower pace of purchases by the Federal Reserve.[6]

The patterns of government financing are given in Table 1. There were no substantive net sales of government coupon securities to the market; the Federal Government relied largely or exclusively on short-term financing. The ratio of short-term interest-bearing public debt (Treasury bills and deposits at the central bank) to GDP is in the range of 40 to 50%, compared with 5% in the United States at the end of 2006, before the global financial crisis.

Table 1: Central government financing, March-November 2020, United States

	Total government borrowing	Sales of coupon securities to market (net)	Financed by (1) Treasury bill sales to market (net)	Central bank purchases of Treasury securities (net)	Ratio of short-term interest-bearing debt (Treasury bills + deposits at central bank) to GDP (%)
United States (USD billion)	3,936	-700 (2)	+2,300 (2)	+2,100 (2)	40

Sources: United States: Government Accountability Office (2020), Federal Reserve System table H4-1. We thank Bill Allen and Richhild Moessner for this data.
Notes:
(1) Some financing items have been omitted, but they are not material in aggregate.
(2) Approximate. Approximations are necessary because some of the data are weekly and some monthly.
(3) Gilts only.
(4) After end of current quantitative easing (QE) programme.

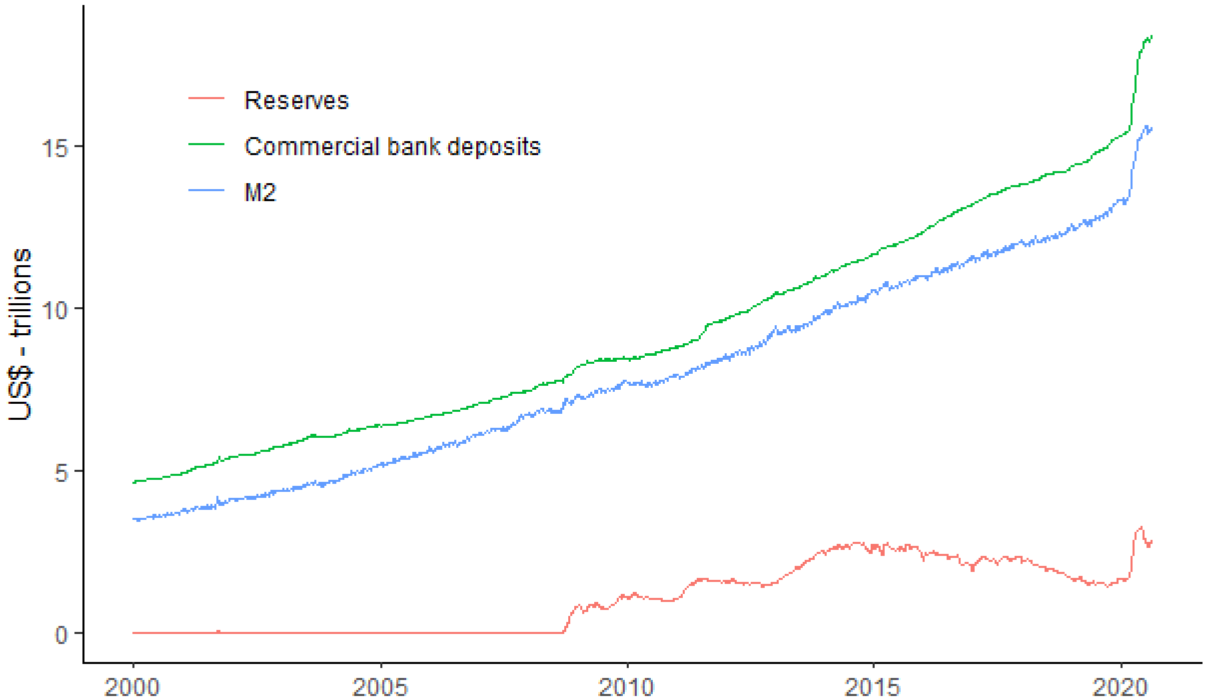
1.2 The lockdown as a shock to velocity of money

The significant increase in the stock of money[7] coupled with the substantial fall in GDP has meant that the velocity of money has fallen dramatically (Figure 4).

[6] Federal Reserve (2020c).

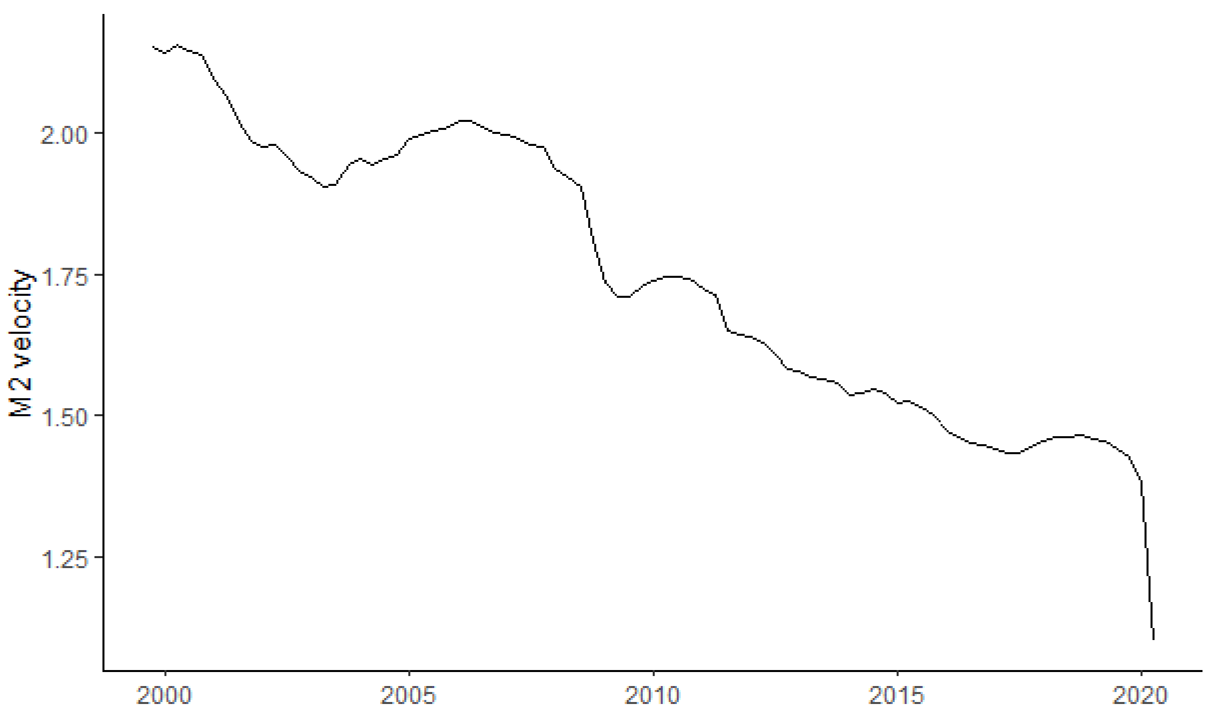
[7] The pandemic led to some extraordinary movements in monetary aggregates (Figure 3). US broad money (M2) increased by USD 3 trillion from the end of February to the final week of August 2020.This was a 20% increase and the largest six-month increase in broad money since at least the 1970s. This increase is reflected in the data on commercial bank deposits which increased 16% over the same period, or by USD 2.1 trillion. The monetary base has also expanded enormously, predominantly through an expansion in reserve balances held at the Fed. At their peak in May 2020, reserves reached USD 3.3 trillion, or USD 1.6 trillion more than they had been at the end of February, ; an increase of 100%. They have subsequently fallen back slightly to USD 2.8 trillion, but that still represents an increase of more than 70% relative to their pre-pandemic levels. The expansion of narrow money has been driven by the Federal Reserve's policy response to the pandemic. On 15 March 2020, after an emergency meeting, the Federal Reserve announced it would purchase USD 700 billion of assets, split between Treasury securities (USD 500 billion) and mortgage-backed securities (USD 200 billion), and that these purchases would be funded by the creation of new reserves, as with other rounds of QE. On 23 March, amid a

Figure 3: US money aggregates



Source: Federal Reserve Bank of St Louis (FRED).

Figure 4: Velocity of US money (M2)



Source: FRED

Between the end of 2019 and the end of the second quarter of 2020, the ratio of M2 to nominal GDP fell more than 30 basis points, from 1.43 to just 1.10 (Table 2). This was a significantly larger and quicker fall in velocity than during the global financial crisis of 2008-09 and was likely to deepen and persist as long as the Federal Reserve continued to expand the monetary base and economic output remained weak.

Table 2: Changes in macro and monetary aggregates: February 2020 - August 2020

	Change (USD billion)	Change (%)
Real GDP		-10
PCE inflation		-0.5
Reserves	1,180	72
M2	3,030	20
Bank deposits	2,145	16

Note: Real GDP is the change between 2019 Q4 and 2020 Q2. Personal Consumption Expenditure (PCE) inflation change is in percentage points.

An important driver of the fall in velocity was the choices of households, which cut spending sharply. Note that there are likely to have been elements of both planned and forced savings and, that although the aggregate income of all households has fallen, a substantial majority of employees have been working and earning income (Bell and Blanchflower, 2020). Total household income did not fall by nearly as much as spending, largely because those who are still employed, working from home or elsewhere cut back on their purchases. Savings jumped as a result, with the personal saving rate increasing to 13.1% in March 2020, from 7.7% in January. And savings increased further over the rest of the spring, in April and early May. While authorities have forced many establishments to close, leaving workers jobless, and issued stay-at home orders ("lockdowns"), consumers also decreased their demand for many services, most likely for precautionary reasons. Furthermore, newly jobless workers reduced their consumption of all goods and services. We summarise the main stylised facts around monetary and macroeconomic variables in the first part of the crisis in Table 2.

1.3 Demand and supply joined at the hip

The pandemic entails both a primitive supply shock and a demand shock, and consequently, a fiscal impulse to support aggregate demand. A demand shock is a reduction in consumers' ability or willingness to purchase goods and services at given prices. People avoiding restaurants for fear

period of market dysfunction, the guidance around these purchases was changed. The Federal Reserve began to buy securities in "the amounts needed" to support smooth market functioning and the transmission of monetary policy.

of contagion or due to stay-at-home orders is an example of a demand shock. In addition, as service sector workers lose jobs and income, they reduce purchases of goods such as cars and domestic appliances, which can also be seen as a sectoral demand shock. A supply shock, on the other hand, is anything that reduces the economy's ability to produce goods and services, at given prices. Shutdown measures prevent workers from doing their jobs and can be interpreted as a supply shock. As stressed in a recent paper (Brinca, Duarte, and Faria-e-Castro, 2020), while most sectors in the United States experienced negative supply shocks, some sectors experienced small positive demand shocks. For example, some retailer benefited when people stopped going to restaurants and started buying more groceries to cook at home.[8] The paper's results suggest that labour supply shocks accounted for most of the fall in hours worked in March and April 2020, but demand shocks were also important.[9]

A further aspect of the crisis was that fiscal policy provided prompt and profound support for the economy and the central bank, rather than responding to the injection of demand by seeking to tighten monetary and financial conditions, created space for the fiscal authority by easing funding costs. This was achieved by reducing the net supply of bonds that had to be absorbed by the private sector and by directly affecting the yield curve by lowering the federal funds rate and making supportive statements about the future stance of policy (see Barwell, Chadha and Grady, 2020).

This paper is organised as follows. Section 2 discusses relevant literature. Section 3 describes the model and outlines our approach to modelling monetary and fiscal responses to the Covid-19 pandemic shocks. Section 4 gives the calibration of the quantitative model, Section 5 outlines the impulse response functions with and without extraordinary monetary interventions in the presence of lockdown, shutdown and fiscal responses. We also show the aggregate path of the economy in a counterfactual analysis with and without the monetary interventions. Section 6 concludes.

2 Related literature

The macroeconomic effects of the Covid-19 shocks are analysed in a number of papers. Eichenbaum, Rebelo and Trabandt (2020) find that people's decision to limit consumption and work effort reduces the severity of the pandemic, as measured in total deaths, but exacerbated the size of the recession caused by the pandemic. Fornaro and Wolf (2020) examine the long-run effect of the supply disruption caused by the Covid-19 shocks: they show that the spread of

[8]The information technology sector also benefited, probably owing to increased interest in telecommuting.

[9]For instance, Shapiro (2020) analyses the dramatic fall in inflation following the onset of the Covid-19 pandemic. Breaking down the underlying price data according to spending category reveals that a majority of the drop in core personal consumption expenditures inflation came from a large decline in consumer demand. This demand effect far outweighed upward price pressure from Covid-19-related supply constraints.

the coronavirus might cause a demand-driven slump, give rise to a supply-demand doom loop, and open the door to long-run stagnation traps induced by pessimistic animal spirits. Baqaee and Farhi (2020) look instead at the short-run business cycle effects of the pandemic shocks and argue that the effects of negative sectoral supply shocks are stronger than those of shocks to the sectoral composition of demand.

Guerrieri et al. (2020) focus specifically on supply shocks, motivated by the shutdowns, and study the induced effects on demand. They argue that the economic shocks associated with the Covid-19 pandemic – shutdowns, layoffs, and firm exits – can amplify the initial effect, thereby aggravating the recession. They find that an optimal policy, closing down contact-intensive sectors and providing full insurance payments to affected workers can achieve the first-best allocation, despite the lower per-dollar potency of fiscal policy. Bigio, Zhang and Zilberman (2020) show that the Covid-19 shocks have lead to a reduction in the demand and supply of sectors that produce goods that need social interaction for their production or consumption and analyse the role played by fiscal lump-sump and credit transfers. Auerbach, Gorodnichenko and Murphy (2020) argue that the effectiveness of such fiscal policies also depend on the level of inequality and on the joint distribution of capital operating costs and firm revenues. In general, inequality has negative effects on output, while also diminishing the effect of a demand-side fiscal stimulus. Significantly, the economic impact of Covid-19 has also been extremely unequal across sectors: del Rio-Chanona et al. (2020) correctly predicted that some sectors would be hit by demand shocks (transport, for instance), some by supply shocks (manufacturing and mining, for instance), and some by both (entertainment, restaurants, and tourism), while some others would be relatively immune (in particular, high-wage occupations).

There were also additional policy proposals in response to the Covid-19 shocks, a large number which were collected in Baldwin and Weder di Mauro (2020). As stressed by Bartsch et al. (2020), neither monetary policy nor fiscal policy by itself can protect the economy from extreme output contractions, job losses and financial turmoil. One emerging conclusion is that a successful stimulus in a pandemic requires fiscal and monetary authorities to create space for each other. As debt rises, monetary stimulus creates fiscal space by setting favorable borrowing terms for the Treasury. However, for this space to be effective, the central bank must also provide reliable monetary support for government debt – primarily to protect debt markets from sudden increases in sovereign risk. With interest rates close to a minimum, the Treasury creates space for monetary stimulus (through QE and other unconventional measures) by providing emergency support to the central bank's budget, so that monetary authorities do not face the risk of losing control over the level of prices, even in the event of large economic losses.

Hofmann et al. (2020) analyse fiscal-monetary interactions when interest rates are very low. The model features conventional monetary policy conducted through the short-term interest rate, central bank balance sheet policies conducted through asset purchases, fiscal policy in the form of a primary deficit rule and government debt accumulation. They further find that systematic balance sheet policies considerably enhance macroeconomic stability in a low interest rate environment as they help the central bank to partly overcome the zero lower bound constraint and preserve fiscal space, thereby rendering countercyclical fiscal policy more effective.

In our paper we push the debate forward and analyse the macroeconomic impact of both shutdowns (supply shocks) and lockdowns (demand shocks) and consider a supportive monetary and fiscal mix in a low interest rate environment that can limit the disruption to output. We show that nonconventional monetary tools may offset the effect of the zero lower bound and provide space for monetary policy to support fiscal stimulus so that much of the output loss is mitigated.

3 The model

We now set out a simple framework for analysing extraordinary central bank and fiscal interventions during the Pandemic. We employ the model by Chadha, Corrado, Meaning and Schuler (2020).[10] The central bank controls the stock of fiat money and banks create intra-private sector claims by the means of loans, L and deposits, D.

We first take a more detailed look at the private sector balance sheet, shown in Table 3. The private sector has three forms of assets: deposits, D, held at banks, some fraction of bonds, γB, issued by government and a fraction of total capital.[11] The liabilities are loans, $D-r$, provided by banks and taxes. Capital lies on the assets side of household balance sheets because households own firms. The fiscal authority issues government bonds, B, which are recorded on its balance sheet as a liability in the form of outstanding public debt, and collects taxes, t. The commercial banks' balance sheet liabilities are deposits, D. Some fraction of liabilities, r, is held as reserves and the rest, $D-r$, is available to be lent to the private sector. The central bank holds assets in the form of some fraction of government bonds, $(1-\gamma)B$, and a fraction of capital, $(1-\gamma_k)K$, with liabilities determined by central bank money, which are bank reserves.[12] The net assets of commercial banks and of the central bank are both zero.

The private sector has net assets given by $D + \gamma B + \ \gamma_k K - (D - r + \sum_{i=0}^{\infty} \beta^i tax_i)$ and so because $r = (1-\gamma)B + \gamma_k K$ and $\sum_{i=0}^{\infty} \beta^i tax_i = B$, we can see that the net private sector assets are K.

From this flow of funds we can see the mechanism by which extraordinary policies operate in the Pandemic. The central bank can implement QE which involves the expansion of its balance sheet through the issuance of bank reserves that are backed by increased holdings of either bonds

[10] For further details, see also Chadha et al. (2020).

[11] In this example we assume that the private sector is represented by households, so firms are included here.

[12] If we operate in an open economy, central bank assets would also include foreign exchange reserves r^f.

Table 3: Balance Sheets

Private Sector			
Assets		Liabilities	
Deposits	D	Loans	$(D-r)$
Bonds	γB	Tax	$\sum_{i=0}^{\infty}\beta^i tax_i$
Capital	$\gamma_k K$		

Fiscal Authority			
Assets		Liabilities	
Tax	$\sum_{i=0}^{\infty}\beta^i tax_i$	Bonds	B

Commercial Banks			
Assets		Liabilities	
Reserves	r	Deposits	D
Loans	$(D-r)$		

Central Bank			
Assets		Liabilities	
Bonds	$(1-\gamma)B$	Reserves	r
Capital	$(1-\gamma_k)K$		

or capital. The bank reserves are lodged with commercial banks against which the private sector, which has sold the bonds or capital to the central bank, has a deposit claim.

When the fiscal authority issues government bonds to finance its deficit this acts as cushion to the fall in GDP. Through bond purchases in the context of QE, the amount of government bonds held by the private sector can be steered, giving fiscal policy further space for stabilisation policies.

We outline our model based on Chadha, Corrado, Meaning and Schuler (2020) which is an extended version of Goodfriend and McCallum (2007). This primarily consists of a Calvo-Yun monopolistically competitive production economy with sticky prices and four main blocks: households, which can work either in the goods-production sector for firms or for banks monitoring loan quality for banks, who meet consumer deposit demand with reserves and a loan production function. As standard there is a monetary authority and a fiscal authority.

3.1 Households

Households are faced with a utility function in real consumption, c_t, and leisure:

$$U = E_0 \sum_{t=0}^{\infty} \beta^t [\phi_t \log(c_t) + (1-\phi_t)\log(1-n_t^s - m_t^s)] \tag{1}$$

They supply labour to the goods production sector, n_t^s, or to financial intermediaries in the form of monitoring work, m_t^s. In our model ϕ_t is subject to the labour supply (shutdown) shock. They are also subject to the budget constraint:

$$q_t(1-\delta)K_t + \frac{\gamma B_t}{P_t^A} + \frac{D_{t-1}}{P_t^A} + w_t(n_t^s + m_t^s) + c_t^A\left(\frac{P_t}{P_t^A}\right)^{1-\theta} + T_t \tag{2}$$
$$-q_t K_{t+1} - \frac{\gamma B_{t+1}}{P_t^A(1+R_t^B)} - \frac{D_t}{P_t^A} - w_t(n_t + m_t) - c_t = 0$$

where q_t is the price of capital, K_t is the quantity of capital, P_t is the price of goods produced by households, P_t^A is the consumption goods price index, n_t is the labour demanded by households as producer, m_t, is the labour demanded by households' banking operations, w_t is the real wage, D_t is the nominal holding of deposits, T_t is a net transfer from the government, R_t^B is the nominal interest rate on the fraction γ of government bonds purchased in period $t+1$, B_{t+1}. We also assume that any profit from the banking sector, Π_t, goes to the household sector. As a producer, the household also pays wages on the hours of work it employs. The Lagrange multiplier of this constraint is denoted as λ_t and θ is the elasticity of household demand.

In addition, households have a "deposit-in-advance" constraint which requires them to hold deposits with a bank in order to implement their consumption plans, where v_t is the velocity of broad money,

$$c_t = v_t D_t / P_t^A. \tag{3}$$

In our model v_t denotes the velocity shock. An important driver of the fall in velocity during the Covid-19 pandemic has been the choice made by consumers, who cut spending sharply during lockdown.

3.2 Banks

The role of banks in our economy is to meet the deposit demand of liquidity constrained consumers confronted with the deposit-in-advance constraint. These deposits are created in two ways: (i) they can be created by the central bank in the form of narrow money (reserves) which is lent to or lodged with commercial banks, or (ii) commercial banks can create deposits themselves by producing loans which generate an equivalent deposit on the liabilities side of the bank's balance sheet. Thus

$$L_t + r_t = D_t \tag{4}$$

and broad money is determined in part by the central bank, but also mostly by the banking system. $\frac{D}{r}$ therefore represents the money multiplier and, as the only source of narrow money in our model is reserves, $\frac{1}{MM} = \frac{r}{D}$, also equals the reserve ratio.[13]

3.2.1 Loans

We abstract from cash and assume that narrow money consists solely of reserves, which in normal times the central bank supplies to commercial banks perfectly elastically in response to their demand. In order to obtain any excess reserves commercial banks face a cost, which is the central bank's policy rate, paid via open market operations conducted at a discount window.[14]

Commercial banks can create deposits by making loans, which generate an equivalent deposit on the liability side of the bank balance sheet, but also incur a cost. Banks produce these loans by applying a production technology to collateral posted by households in the form of bonds, b_t, or capital, $q_t K_t$. This process is captured by a Cobb-Douglas production function for loans where collateral is combined with monitoring work, m:

$$L_t/P_t^A = F(\gamma b_{t+1} + A3_t k q_t K_{t+1})^{\alpha} (A2_t m_t)^{1-\alpha} \quad 0 < \alpha < 1, \tag{5}$$

$A2_t$ denotes a shock to monitoring work, $A3_t$ is a shock on capital as collateral and $b_{t+1} = B_{t+1}/P_t^A(1 + R_t^B)$. The parameter k denotes the inferiority of capital as collateral in the banking production function,[15]while α is the share of collateral in loan production. Increasing monitoring effort is achieved by increasing the number of people employed in the banking sector and consequently reducing employment in the goods production sector. One channel that policy can affect is to limit the increase in the costs of loan provision as workers move from goods production to loan monitoring.

Commercial banks seek to maximize total returns within the period subject to the returns from loans, L_t, which are lent out at the collateralized interest rate of R_t^L, and the payment of interest on deposits, R_t^D:

$$\max \Pi_t = R_t^L L_t - R_t^D D_t - w_t m_t, \tag{6}$$

with m_t refering to monitoring work employed.

3.3 Conventional and unconventional monetary policy

The central bank policy rate, R_t, is the market clearing rate for reserves and is set by a feedback rule responding to inflation, π_t, and output, y_t, with parameters, ϕ_π and ϕ_y, respectively. Policy

[13] Under a 100% reserve system, the broad money supply, and thus consumption within our model, would be restricted by the creation of narrow money by the central bank. But here $D_t = r_t$ and the subsequent problem of reserve demand simplifies to depend purely on demand for consumption at the given policy rate.

[14] See Freeman and Haslag (1996).

[15] Capital is considered inferior as there are increased costs to the bank of verifying its physical quality and condition as well as its market price. It is also less liquid should it be needed in the event of default.

rates are smoothed so that $1 > \rho > 0$. The policy rule is active until the central bank interest rate on reserves reaches the zero lower bound (assumed to coincide with the effective lower bound in this model setup). We incorporate active QE policy by assuming that the central bank adopted the following countercyclical feedback rule with the size of reserves, r_t, as the policy variable, with $\bar{r}$ being the steady state reserves, ψ_y and ψ_π being the weights of output and inflation in the policy function.

$$\begin{cases} R_t = R_{t-1}^{\rho} \left(\frac{y_t}{y}\right)^{(1-\rho)\phi_y} \left(\frac{\pi_t}{\pi}\right)^{(1-\rho)\phi_\pi} & \text{for } R_t > 0 \\ r_t = \bar{r}(r_{t-1})^{\rho_r} \left(\frac{y_t}{y}\right)^{-\psi_y(1-\rho_r)} \left(\frac{\pi_t}{\pi}\right)^{-\psi_\pi(1-\rho_r)} & \text{for } R_t = 0 \end{cases} \tag{7}$$

We model open market operations in which an asset, primarily bonds, is bought from the private sector in exchange for newly created money.[16] The central bank now holds more bonds on its balance sheet. The private agent from whom the bonds have been purchased receives a newly created deposit in its account with its commercial bank, while that commercial bank's own account with the central bank is credited with an equal increase of freshly created reserves.[17] We assume that the central bank does not react to the loss in collateral value in real time.[18] To incorporate this mechanism into our model we assume the central bank must match its only liability, reserves, by holding just one class of assets, government bonds, B_t.

3.4 Fiscal spending and debt absorption

For the fiscal authority we assume two different regimes: normal times and discretionary fiscal spending. In normal times, in this model, the fiscal authority follows a balanced budget rule, i.e. the total supply of government bonds is fixed. This is reflected in the following government rule:

$$T_t = g_t - tax_t = \frac{B_t}{P_t^A(1 + R_{t-1}^B)} - \frac{B_{t-1}}{P_t^A} \tag{8}$$

where g_t is government spending and tax_t is a lump sum tax. The fiscal authority chooses the level of its deficit. We can fix the level of government debt as a constant but also shock the

[16] The mechanism outlined here abstracts from sterilized open market operations in which the purchases of assets are funded by the sale of other assets on the central bank's balance sheet rather than the creation of new reserves and instead acts through "credit easing" channels as defined by Bernanke (2009).

[17] We abstract from the possibility of banks themselves holding bonds and acting as the central bank's counterpart in an open market operation. While this would be closer to how traditional open market operations have been carried out, it is not consistent with recent large-scale asset purchases carried out by central banks that avoided buying assets directly from banks. In the context of our model, the distinction between the two frameworks is of little importance.

[18] Wu and Xia (2015), among others, calculate shadow rates from long-term yields of government bonds during phases of QE where the policy rate was at the zero lower bound. In principle, a QE rule could link the size of monetary intervention to the desired shadow rate. As the model setup incorporates only short-term bonds, we apply the reserves rule.

level should the government choose to run a deficit. Under discretionary fiscal spending, such as during a large external shock like the pandemic, the stock of debt increases. Discretionary fiscal spending enters through an exogenous increase in government debt, $a6_t$, i.e. in log linear form

$$\widehat{B}_t = a6_t. \tag{9}$$

While during the global financial crisis the provision of liquidity followed bank demand and concerns about subdued inflation and the the economic recovery, the motivation for QE also included the goal of stabilising market function. In the environment during the pandemic this would include also potential repercussions of the large issuance of government debt during the Covid-19 pandemic.[19] We incorporate this accommodative stance by further assuming a rule that keeps the reserve to deposit ratio constant in response to a discretionary fiscal expansion:[20]

$$\Delta r_t = \Delta D_t(a6_t) \tag{10}$$

The result of adopting this rule is that it creates fiscal space by buying up a substantial share of the new issuance of bonds. An expansionary fiscal shock would increase GDP and, all else being equal, that would tend to induce the central bank to lower reserves and become more restrictive as in equation (7). Through additional QE, the central bank absorbs a significant share of the additional bonds issued, B_t, in order to stabilise bond prices and interest rates. The accumulation of reserves and higher bond prices supports the provision of loans. Thus, by matching the increase in deposits, D_t, from fiscal policy with an increase in reserves, r_t, the central bank can augment the positive shock from discretionary fiscal spending.

When the central bank buys bonds in an open market operation, it increases the fraction of the total bond supply which it holds and decrease that held by the private sector. We can therefore define total bond holdings as the sum of central bank and private sector bond holdings,

$$b_t = b_t^{CB} + b_t^P, \tag{11}$$

where $b_t^{CB} = B_t^{CB}/P_t^A(1+R_{t-1}^B)$ and $b_t^P = B_t^P/P_t^A(1+R_{t-1}^B)$. As central bank bond holdings must equal reserves, we can substitute and re-arrange this equation to give the log linear relationship

$$b_t^p \hat{b}_t^p = b_t \hat{b}_t - r_t \hat{r}_t \tag{12}$$

It is this newly defined variable b^p which determines the amount of collateral households have available and thus b^p which features in our equations for loan supply and the marginal value of

[19] See Federal Reserve (2020a), which refers to a need "to support smooth market functioning".

[20] The adopted rule keeps monetary policy neutral in that it does not counteract the output and inflation increase induced by discretionary fiscal spending, but provides adequate reserves to the banking system to allow for the discretionary fiscal spending to take its full effect.

collateralised lending as well as the consolidated government budget constraint.[21]

3.5 Firms

The production sector, characterized by monopolistic competition and Calvo pricing, employs a Cobb-Douglas function with capital, K_t, and labour, n_t, subject to productivity shocks. Firms decide the amount of production they wish to supply and the demand for labour by equalizing sales to net production:

$$K_t^{\eta}(A1_t n_t)^{1-\eta} - c_t^A (P_t/P_t^A)^{-\theta} = 0, \tag{13}$$

where η denotes the capital share in the firm production function, $A1_t$ is a productivity shock in the goods production sector whose mean increases over time at a rate ϖ and θ denotes the elasticity of aggregate demand, c_t^A. The Lagrange multiplier of this constraint is denoted as, ξ_t.

3.6 Labour Market

The labour market is characterised by demand from production firms and from the banking sector. By clearing the household and production sectors,[22] we can define the equilibrium in the labour market. Firm's demand for labour is:

$$w_t = \frac{\xi_t}{\lambda_t} A1_t (1-\eta) \left(\frac{K_t}{n_t A1_t} \right)^{\eta} \tag{14}$$

Banks demand for monitoring work:

$$w_t = \left(\frac{\phi}{\lambda_t c_t} - 1 \right) \frac{1-\alpha}{m_t} c_t \tag{15}$$

which depends negatively on wages, w_t, and positively on consumption, c_t, and where $1-\alpha$ is the share of monitoring in the loan-production function.

The total supply of labour by households is given by:

$$n_t^s + m_t^s = 1 - \left(\frac{1-\phi}{w_t \lambda_t} \right) \tag{16}$$

which depends positively on wages w_t, which is the same for the two types of labour, and on the shadow value of consumption, λ_t. By clearing the household and production sectors, we can define the equilibrium in the labour market and in the goods market.

[21] As we are dealing with a consolidated government budget constraint, the net effect of interest payments on bonds held by the central bank is zero.

[22] For details on the model set-up, derivation and notation see the technical appendix.

3.7 Interest rates spreads

The inclusion of this banking sector gives rise to a number of interest rates and financial spreads. The benchmark theoretical interest rate R^T is the standard intertemporal nominal pricing kernel, priced from expected real consumption growth and inflation. Basically it boils down to a one-period Fisher equation:

$$R_t^T = E_t(\lambda_t - \lambda_{t+1}) + E_t\pi_{t+1}. \tag{17}$$

To find the excess of the loan rate, R^L, over funding costs, R, as the real marginal cost of loan production, we divide the factor price, $\frac{w_t}{P_t^A}$, by the marginal product of labour which equates to the marginal product of loans per unit of labour $(1-\alpha)\frac{L_t}{m_t}$ where loans are defined by the following relationship $L_t = D_t(1-rr_t) = \frac{c_t P_t^A}{v_t}(1-rr_t)$:

$$EFP_t = \frac{w_t v_t m_t}{(1-\alpha)(1-rr_t)c_t}.$$

Therefore, in log-linear form the interest rate on loans, R_t^L, is greater than the policy rate by the extent of the external finance premium.

$$R_t^L - R_t = \underbrace{[v_t + w_t + m_t + rr_t - c_t]}_{EFP_t}. \tag{18}$$

The external finance premium, EFP_t, is the real marginal cost of loan management, and it is increasing in velocity, v_t, real wages, w_t, monitoring work in the banking sector, m_t, and the reserve ratio, rr_t, and decreasing in consumption, c_t. As $rr_t = \frac{1}{MM_t}$ the EFP is also decreasing in the money multiplier, meaning that in this model, banks switch to narrow money taking more of the burden of meeting deposit demand, when the EFP is higher.

The yield on government bonds is derived by maximizing households' utility with respect to bond holdings, $R_t^T - R_t^B = \left[\frac{\phi}{c_t\lambda_t} - 1\right]\Omega_t$. In its log-linear form, it is the risk-free rate, R_t^T, minus the liquidity service on bonds, which can be interpreted as a liquidity premium (LP):

$$R^B R_t^B = R^T R_t^T - \underbrace{\left[\left(\frac{\phi}{c\lambda} - 1\right)\Omega\Omega_t - \frac{\phi_t\Omega}{c\lambda}(c_t + \lambda_t)\right]}_{LP_t}, \tag{19}$$

where $(c_t + \lambda_t)$ measures the household marginal utility relative to households' shadow value of funds, while Ω_t is the marginal value of the collateral. It is in fact these key margins - the real marginal cost of loan management and the liquidity service yield - that determine the behaviour of spreads. In the above expression, ϕ denotes the consumption weight in the utility function and λ_t is the shadow value of consumption, c_t. The interest rate on deposits is the policy rate, R_t, minus a term in the reserve/deposit ratio:

$$R_t^D = R_t - \frac{rr}{1-rr} rr_t. \tag{20}$$

As these spreads influence the asset allocation of banks they also have an impact on the resulting path of consumption. When we come to the analysis of the model we will discuss these premia as a way of understanding our results.

4 Calibration

Table 4 describes the model variables, Table 5 reports the values for the parameters and Table 6 the steady-state values of relevant variables.[23]

Following Goodfriend and McCallum (2007), we choose the consumption weight in utility, ϕ, to yield one-third of available time in either goods or banking services production. We also set the relative share of capital and labour in goods production, η, at 0.36. We choose 11 for the elasticity of substitution of differentiated goods, θ. The discount factor, β, is set at 0.99, which is close to the canonical quarterly value, while the mark-up coefficient in the Phillips curve, κ, is set at 0.1. The depreciation rate, δ, is set at 0.025, while the trend growth rate, ϖ, is set at 0.005, which corresponds to 2% per year. The steady-state value of bond holding level relative to GDP, b, is set at 0.56 as of the third quarter of 2005. The steady state of private sector bond holdings relative to GDP is set at 0.50, consistent with average holdings of US Treasury securities since the mid 2000s.[24]

The deep parameters linked to money and banking are defined as follows. Velocity at its steady state-level is set at 0.276, which is close to the average ratio of US GDP to M3 given by 0.31. The fractional reserve requirement, rr, is set at 0.1. This is consistent with the reserve ratio set by the Federal Reserve on all liabilities above the low reserve tranche and approximately equal to the average Tier 1 capital ratio in the United States since the mid 2000s.

This allows us to manipulate three key deep parameters which may influence the rest of the steady-state variables. Interestingly, these are three financial variables and are thus of particular relevance for our debate on policies. α is the Cobb-Douglas weight of collateral in loan production. This is the degree to which banks base their lending on collateral as opposed to monitoring work or information based-lending. The benchmark calibration of 0.65 is within a range throughout the literature of 0.6 to 0.89 (Zhang, 2011), so this is what we follow. k is the degree to which capital is less efficient as collateral than bonds, as it entails higher costs to the bank in order to check its physical condition and market price. It is also less liquid should default occur and the collateral be called upon to repay the value of the loan. We set this parameter at 0.2, which

[23] The equations for the steady-state values are listed in the technical appendix.

[24] The steady state of the transfer level, the Lagrangian for the production constraint and base money depend on the above parameters. The steady state of the marginal cost is $mc = \frac{\theta-1}{\theta}$.

Table 4: List of Variables

Variable	Description
c	Real consumption
n	Labour input
m	Labour input for loan monitoring, or "Banking employment"
w	Real wage
q	Price of capital goods
P	Price level
π	Inflation
mc	Marginal cost
r	Reserves
rr	Reserves/Deposit ratio
D	Deposits
L	Loans
P^A	Aggregate prices
b	Real bond holding
b^p	Real private sector bond holdings
Ω	Marginal value of collateral
EFP	Uncollateralised external finance premium (R^T - R^{IB})
LSY^B	Liquidity service on bonds
LSY^{KB}	Liquidity service on capital ($kLSY^B$)
R^T	Benchmark risk free rate
R^B	Interest rate for bond
R	Policy rate
R^L	Loan rate
R^D	Deposit rate
λ	Lagrangian for the budget constraint (shadow value of consumption)
ξ	Lagrangian for the production constraint
T	Real transfer (%)

Table 5: Parameterization

Parameter	Description	Value
β	Discount factor	0.99
κ	Coefficient in Phillips curve	0.1
α	Collateral share of loan production	0.65
ϕ	Consumption weight in utility	0.4
η	Capital share of firm production	0.36
δ	Depreciation rate of capital	0.025
ϖ	Trend growth rate of shocks	0.015
ρ	Interest rate smoothing	0.8
ϕ_π	Coefficient on Inflation in Policy	1.5
ϕ_y	Coefficient on Output in Policy	0.5
F	Production coefficient of loan	9.14
k	Inferiority coefficient of capital as collateral	0.2
θ	Elasticity of substitution of differentiated goods	11

is validated by data on the Term Securities Lending Facility, which found that less liquid assets were swapped for bonds in a ratio of 0.21 to 1. F, can be thought of as total factor productivity in loan production, or a measure of the efficiency with which banks use the factors of production to produce loans.[25] We set this to ensure the rest of our steady-state values meet three criteria as closely as possible:

- a 1% per year average short-term real "risk-free rate" which is the benchmark in the finance literature;
- a 2% average collateralised EFP, which is in line with the average post-war spread of the prime rate over the federal funds rate in the United States;
- a share of total US employment in depository credit intermediation in August 2005 of 1.6%, as reported by the Bureau of Labor Statistics.

The value this yields is $F = 9.14$. With these parameter values we see that the steady state of labour input, n, is 0.31, which is close to one-third as required. The ratio of time working in the banking service sector, $\frac{m}{m+n}$, which is 1.9% under the benchmark calibration, is not far from the 1.6% share required. As the steady-states are computed at zero inflation we can interpret all the rates as real rates. The risk-free rate, R^T, is 6% per year. The interbank rate, R, is 0.84%

[25] Some authors have also described it as a measure of credit conditions within the economy. The rationale for this seems plausible as banks will require more collateral when credit conditions are tight and will employ more monitoring work to provide the same amount of loans to the economy.

Table 6: Steady-state parameters

Steady-state	Description	Value
m	Banking employment	0.0063
n	Labour input	0.3195
R^T	Risk free rate	0.015
R^{IB}	Interbank rate	0.0021
R^L	Loan rate	0.0066
R^B	Bond rate	0.0052
b/c	Bond to Consumption ratio	0.56
b^p/c	Private sector bond holdings/Consumption	0.50
γ (b^p/b)	Fraction of bonds held by the private sector	0.893
c	Consumption	0.8409
T/c	Transfers/Consumption	0.126
w	Real wage	1.9494
λ	Shadow value of consumption	0.457
ϕ_y	Coefficient on Output in Policy	0.5
ν	Velocity	0.31
Ω	Marginal value of collateral	0.237
K	Capital	9.19
K^P	Private sector capital holdings	9.19
rr	Reserve ratio	0.1
r/c	Reserves/Consumption	0.36

per year, which is close to the 1% per year average short-term real rate. The government bond rate, R^B, is 2.1% per year. Finally, the collateralised EFP is 2% per year, which is in line with the average spread of the prime rate over the federal funds rate in the United States. The model is solved using the method of King and Watson (1998) who also provide routines to derive the impulse responses of the endogenous variables to different shocks, to obtain asymptotic variance and covariances of the variables and to simulate the data. We calibrate the Covid-19 shocks so that the demand shock dominates to some degree (see Shapiro, 2020). Table 7 reports the calibration of the composite shock.

Table 7: Calibration of Covid-19 shocks

	Volatility σ	Size of shock in σ	Persistence ρ
Velocity of money	0.01	-25%	0.95
Labor supply disutility	0.03	5%	0.25
Policy rate	0.0082	-1%	0.3
Fiscal	0.03	11%	0.95

Note: Calibrated values according to long-run averages. Size of the shock calibrated to match movements of US variables during H1 2020.

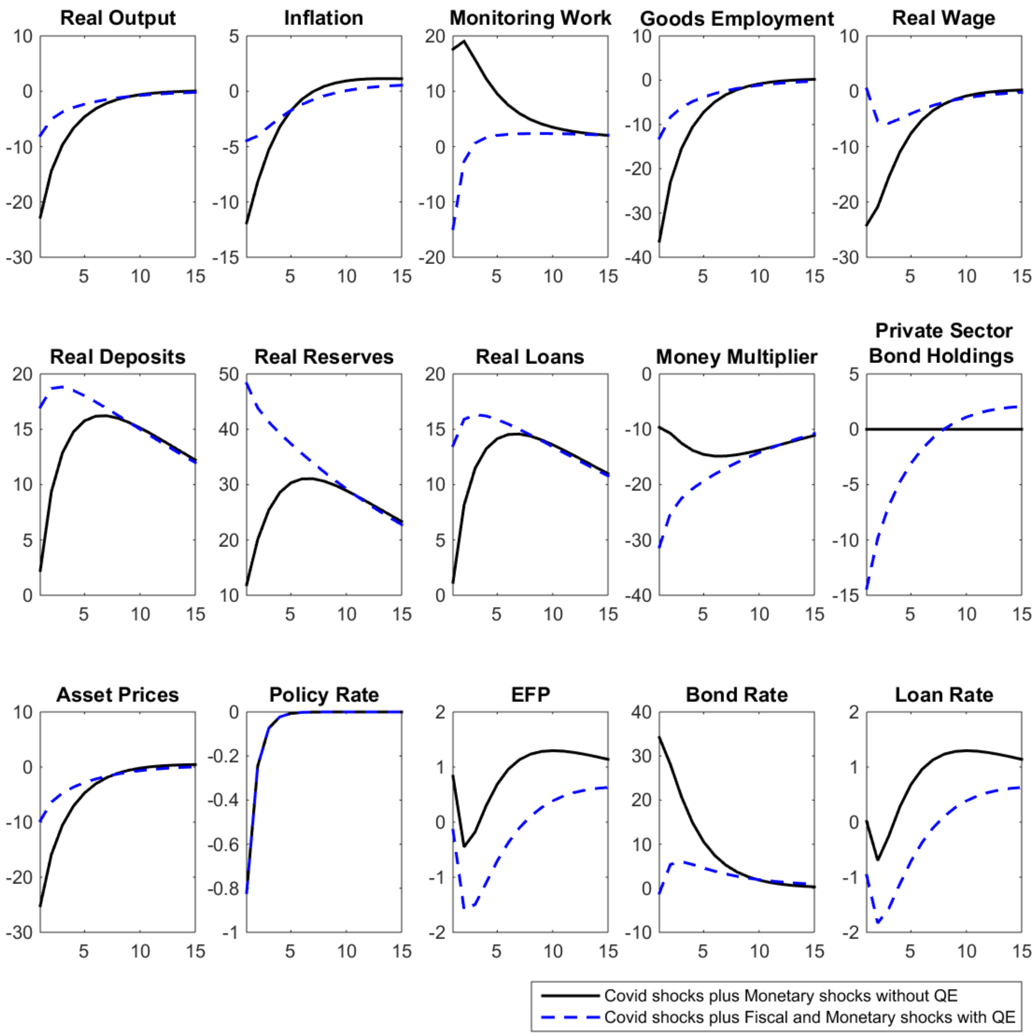
5 Impulse response functions

We first show the combined pandemic shock by aggregating the impact of shutdown, lockdown and fiscal policies and then decompose it into the individual contributions.

5.1 Combined Covid-19 shocks with fiscal shock and QE

Figure 5 shows the combined effect of the lockdown shock and the shutdown shock calibrated to the impact of the Covid-19 pandemic shocks in the United States. We compare the case, where the Federal Reserve deploys QE to respond to these shocks (dashed line) with the counterfactual that involves no deployment of asset purchases to respond to macroeconomic shocks (solid line). The combined shock in the case of no QE intervention has a strong effect on real output and goods employment which drop by more than 20% and 30%, respectively. Asset prices plummet by almost 25%. While the fiscal stimulus mitigates some of the fall, without monetary accommodation, the expansion of government debt, visible through a 10% increase in private sector bond holdings, leads to a large increase in the bond rate. While the EFP reaches 1% on impact, it drops temporarily due to intervention, and stabilises at 1% in the long run. The policy rate reaction, which mimics the rate cut by the Federal Reserve, completely mitigates this initial increase in the EFP. As loans increase while collateral is falling, given strongly reduced asset prices, monitoring work jumps by 20%. Real reserves rise mostly with the increase in real deposits.

Figure 5: Combined Covid-19 shock with fiscal and monetary response



Note: All interest rates are shown as absolute deviations from the steady state, expressed in percentage points. All other variables are percentage point deviations from the implied steady state value. EFP means external finance premium. QE means quantitative easing.

In the case of intervention by the Federal Reserve through large-scale asset purchases (QE), reserves increase on impact by 45%. This has a direct effect on the fall in asset prices which is limited to 10% on impact and to 5% in the following quarter. QE intervention more than absorbs the increase in bonds through the fiscal intervention such that private sector bond holdings fall by more than 10%. This intervention has many benign effects on the economy. The bond rate increase is now limited, as is the increase of the EFP, and as a consequence the loan rate drops and then stabilises around a neutral rate. These effects allow loans to expand with positive effects on activity and inflation. Goods employment and real wages are to a large extent stabilised. Through the stabilization of wages, the effect on inflation is also mitigated to an average drop of 1.5% in the first year after the shocks.

The results show that if the Federal Reserve had not intervened, output would have fallen by more than 10% more on impact and in the following quarter. Real wages may have fallen by more than 15% more and unemployment may have increased by more than 20%. Wages would be 20% lower than with QE. As a result, inflation would fall by substantially more, and the recovery would probably have taken up to twice as long.

5.2 Breaking down the Covid-19 crisis into individual shocks

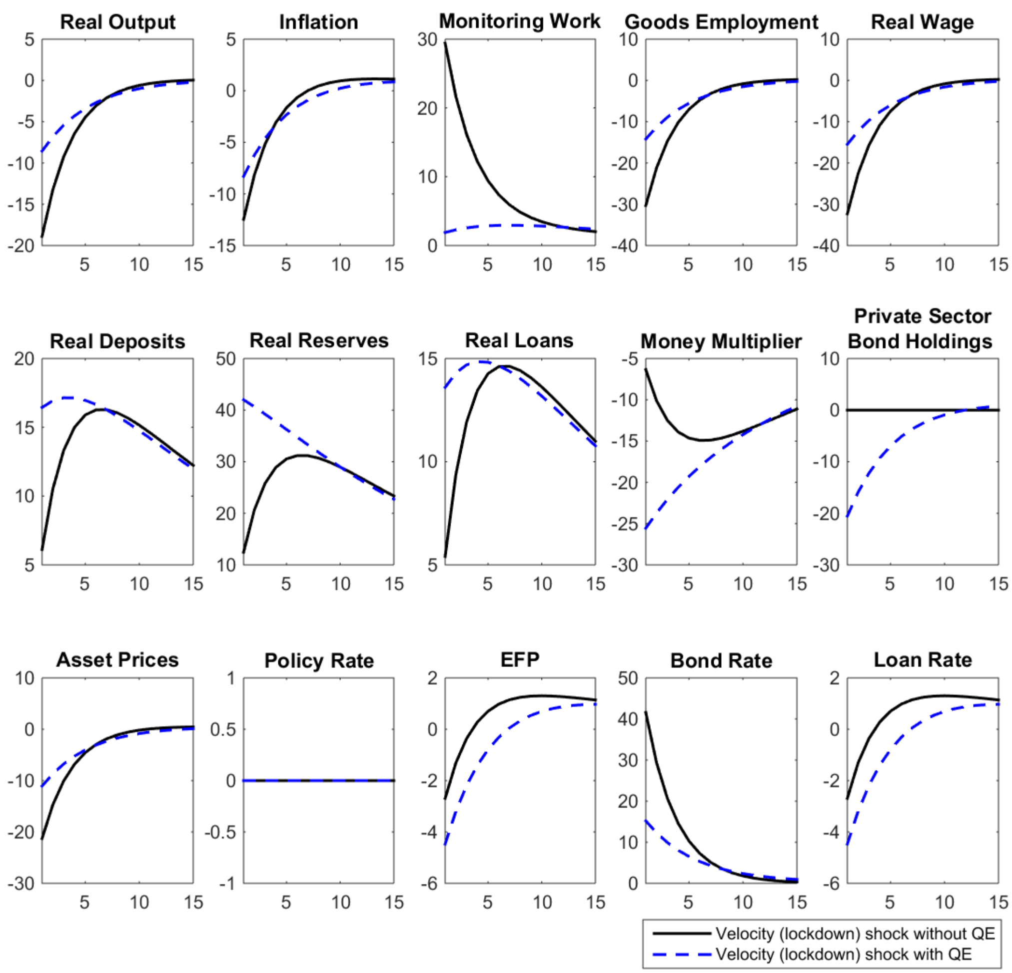
Disentangling the overall Covid-19 shock, we plot the individual simulations for (i) the velocity (or lockdown) shock (Figure 6) and (ii) the labor supply (or shutdown) shock (Figure 7). We show a pure fiscal shock with and without the accommodating monetary policy stance (Figure 8).

Figure 6 displays the response of economic variables to the "lockdown shock" in isolation. We have implemented this as a shock to the velocity of money which generates an increase in deposits, but a fall in output and inflation at the same time. This reflects the observation that households were not able to consume goods and services in aggregate to the same extent as a result of government restrictions and personal choices on social distancing and, accordingly, they accumulated additional deposits in their bank accounts. The main channel of this shock is an increase in deposits, while real output and inflation decrease as aggregate demand falls. Asset prices fall due to the sharp fall in output. We note that a policy reaction through QE helps stabilise asset prices via an increase in reserves, which attenuates the deleterious effect on output and inflation.

Figure 7 shows the "shutdown shock" in isolation. This is a shock to goods sector employment as factories are shut due to restrictions and/or cannot produce due to supply chain disruptions, and thus employees are not able to work. The main effect is a decrease in real output with asset prices falling due to the collapse in activity. By contrast, the effect on inflation is positive. However, given the fall in output, asset prices, deposits and loans contract. We show that prompt intervention by the central bank in increasing reserves can dampen the impact of this shock.

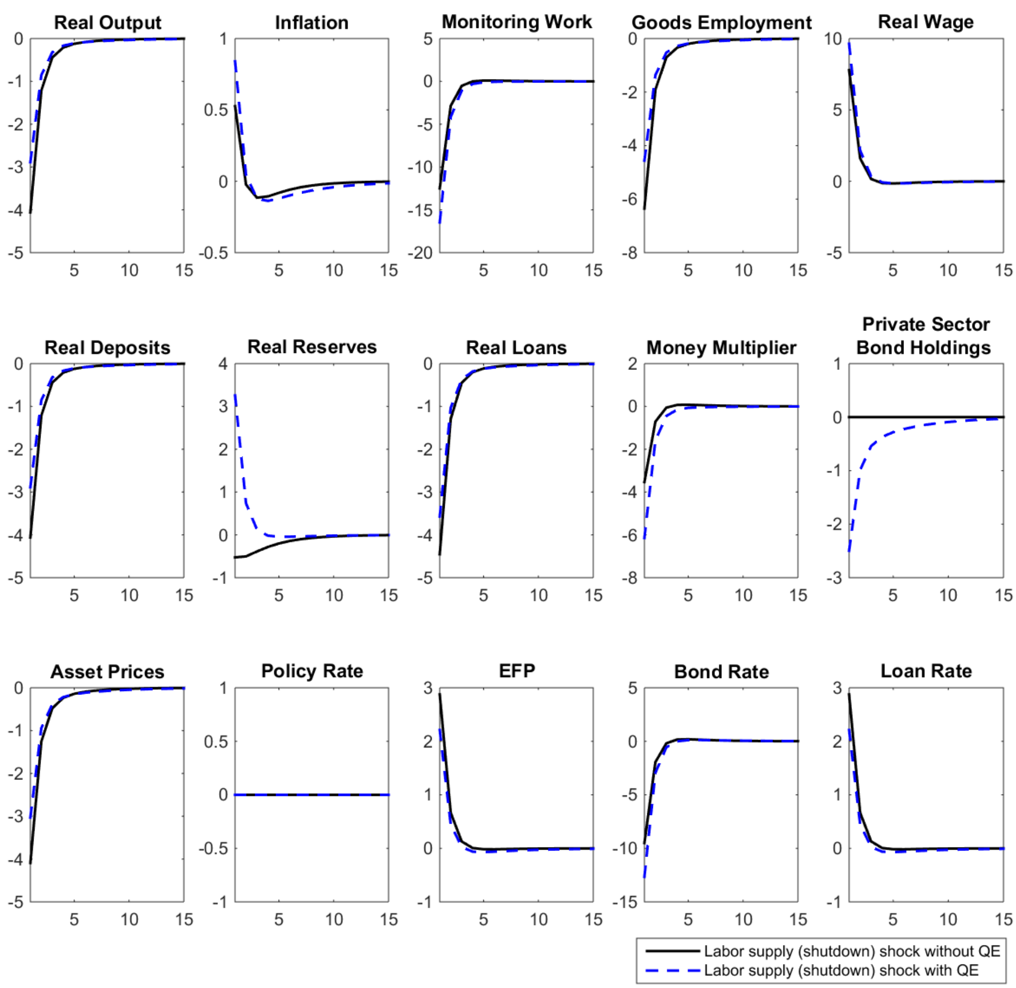
Finally, Figure 8 shows the response of the economy to a fiscal intervention. By engaging in QE, the central bank can keep the government bond rates at a lower level than otherwise. In a more standard setting, monetary policy may limit the efficacy of the fiscal intervention by tightening monetary and financial conditions, but here we introduce a loosening or accommodation of the fiscal impulse that amplifies the effectiveness of the fiscal stabilisation. In this set-up, the central bank accommodates the increase in government debt through an expansion of reserves

Figure 6: Covid-19 lockdown shock with QE response



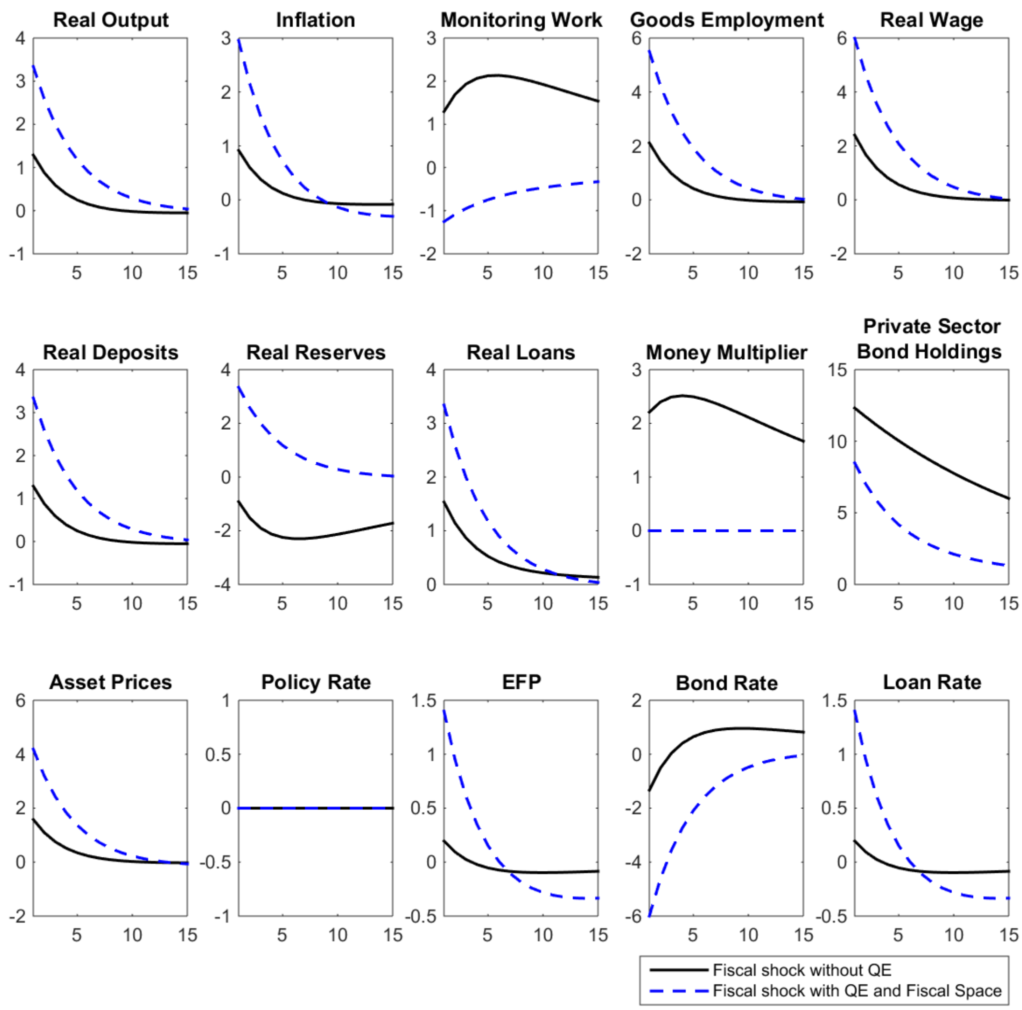
Note: All interest rates are shown as absolute deviations from the steady state, expressed in percentage points. All other variables are percentage point deviations from the implied steady state value. EFP means external finance premium. QE means quantitative easing.

Figure 7: Covid-19 shutdown shock with QE response



Note: All interest rates are shown as absolute deviations from the steady state, expressed in percentage points. All other variables are percentage point deviations from the implied steady state value. EFP means external finance premium. QE means quantitative easing.

Figure 8: Fiscal shock with QE response



Note: All interest rates are shown as absolute deviations from the steady state, expressed in percentage points. All other variables are percentage point deviations from the implied steady state value. EFP means external finance premium. QE means quantitative easing.

rather than tightening the monetary policy stance. This acts to increase reserves alongside broad money and creates fiscal space that in turn supports activity, goods employment, wages and inflation. As asset prices increase this reduces the need for costly monitoring work in the financial sector, allowing lending to proceed with a relatively elastic supply schedule.

6 Conclusions

The 2020 pandemic had the features of a perfect storm: a supply (shutdown) and demand shock (lockdown), which halted the functioning of the global economy for several months. We examine the critical role of monetary policy in offsetting these shocks and in particular in providing support for the fiscal policy interventions. We examine and calibrate the responses of the Federal Reserve in the United States, but the results can be generally interpreted as reflecting the supportive policies adopted by major central banks. We are able to match stylised facts in the United States by implementing a shock to the velocity of money and to labour supply. We show that a combined fiscal-monetary response may have helped avoid turning the Covid-19 crisis into an economic recession of even greater magnitude and severity. Our calibrated model shows that if the Federal Reserve had not intervened, output would have fallen by more than 10% more on impact and in the following quarter. Real wages would be down by more than 15% more and unemployment up by more than 20%. Wages would be 20% lower than with QE. As a result inflation would have fallen even further. Hence, we find that prompt, combined fiscal-monetary interventions mitigated the impact of the pandemic shocks and helped to establish a more rapid recovery to pre-crisis levels of activity.

References

[1] Allen, W. (2021), "Monetary Policy and Government Debt Management during the Coronavirus Pandemic", National Institute Economic Review, 255.

[2] Auerbach, A.J., Gorodnichenko, Y., Murphy, D. (2020). "Inequality, Fiscal Policy and Covid-19 Restrictions in a Demand-determined Economy", NBER Working Paper 27366, National Bureau of Economic Research, Cambridge, MA.

[3] Baldwin, R. and Weder di Mauro, B. (2020), *Economics in the Time of Covid-19*, VoxEU CEPR Press.

[4] Baqaee D. and Farhi, E. (2020), "Supply and Demand in Disaggregated Keynesian Economies with an Application to the Covid-19 Crisis", NBER Working Paper Series, No 27152, National Bureau of Economic Research, Cambridge, MA.

[5] Bartsch, E., Bénassy-Quéré, A., Corsetti, G. and Debrun X. (2020), "It's All in the Mix: How Monetary and Fiscal Policies Can Work or Fail Together", Geneva Reports on the World Economy, No 23, CEPR Press.

[6] Barwell, R., Chadha, J.S. and Grady, M. (2020), "Monetary Policy in Troubled Times: New Governor, New Agenda", NIESR Occasional Paper Series, No 59.

[7] Bell, D.N.F. and Blanchflower, D.G. (2020), "US and UK Labour Markets before and during the Covid-19 Crash", *National Institute Economic Review*, No. 252.

[8] Bigio, S., Zhang, M. and Zilberman, E. (2020), "Transfers vs Credit Policy: Macroeconomic Policy Trade-offs during Covid-19. NBER Working Paper Series, No 27118, National Bureau of Economic Research, Cambridge, MA.

[9] Brinca, P., Duarte, J.B. and Faria e Castro, M. (2020), "Is the COVID-19 Pandemic a Supply or a Demand Shock?", *Economic Synopses*, No. 31,Federal Reserve Bank of St Louis, available at https://doi.org/10.20955/es.2020.31.

[10] Bullard, J. (2021), "Monetary Policy and Fiscal Policy Responses to the COVID-19 Crisis", *Regional Economist*, Fourth Quarter 2020, Federal Reserve Bank of St Louis, November, available at https://www.stlouisfed.org/publications/regional-economist/fourth-quarter-2020/monetary-policy-fiscal-policy-responses-covid-crisis

[11] Chadha, J.S., Corrado, L., and Meaning, J. (2012), "Reserves, Liquidity and Money: An Assessment of Balance Sheet Policies", *BIS Paper* No. 66.

[12] Chadha, J.S., Corrado, L., Meaning, J. and and Schuler, T. (2020), "Bank reserves and broad money in the global financial crisis: a quantitative evaluation", ECB Working Paper Series, No 2463.

[13] Del Rio-Chanona R.M., Mealy, P., Pichler, A., Lafond, F. and Farmer, J.D. (2020), "Predicting the Supply and Demand Shocks of the COVID-19 Pandemic: An Industry and Occupation Perspective", VoxEU CEPR Press.

[14] Eichenbaum, M.S., Rebelo, S. and Trabandt, M. (2020), "The Macroeconomics of Epidemics", NBER Working Paper 26882, National Bureau of Economic Research, Cambridge, MA.

[15] Federal Reserve (2020a), "Federal Reserve announces extensive new measures to support the economy", https://www.federalreserve.gov/newsevents/pressreleases/monetary20200323b.htm

[16] Federal Reserve (2020b), "Federal Reserve issues FOMC statement", https://www.federalreserve.gov/newsevents/pressreleases/monetary20201216a.htm

[17] Federal Reserve (2020c), "Federal Reserve issues FOMC statement", https://www.federalreserve.gov/newsevents/pressreleases/monetary20200916a.htm

[18] Freeman, S. and Haslag, J. (1996), "On the Optimality of Interest-bearing Reserves in Economies of Overlapping Generations", *Economic Theory*, 7(3), pp 557-565.

[19] Goodfriend, M. and McCallum, B.T. (2007), "Banking and Interest Rates in Monetary Policy Analysis: A Quantitative Exploration", *Journal of Monetary Economics*, Vol. 54, pp 1480-1507.

[20] Guerrieri, V., Lorenzoni, G., Straub, L. and Werning, I. (2020), "Macroeconomic Implications of Covid-19: Can Negative Supply Shocks Cause Demand Shortages?", NBER Working Paper Series 26918, National Bureau of Economic Research, Cambridge, MA.

[21] Hofmann, B., Lombardi, M.J., Mojon, B. and Orphanides, A. (2020), "Fiscal-monetary Policy Interactions in a Low Interest Rate World. mimeo.

[22] Shapiro, A.H. (2020), "Monitoring the Inflationary Effects of COVID-19", *FRBSF Economic Letter*, 2020-24, Federal Reserve Bank of San Francisco, available at https://www.frbsf.org/economic-research/publications/economic-letter/2020/august/monitoring-inflationary-effects-of-covid-19/.

[23] U.S. Treasury (2020), "Treasury International Capital Data for March", https://home.treasury.gov/news/press-releases/sm1009

A Model

A.1 Initial maximisation problems

Utility Function

$$U = E_0 \sum_{t=0}^{\infty} \beta_t \left[\phi_t \log(c_t) + (1-\phi_t)\log(1 - m_t^s - n_t^s)\right] \tag{A.1}$$

where c_t is real consumption, m_t^s is the supply of labour to the banking sector and n_t^s is the supply of labour to the goods production sector. Household budget constraint (HBC)

$$\begin{aligned} & q_t(1-\delta)K_t + \frac{\gamma B_t}{P_t^A} + \frac{D_{t-1}}{P_t^A} + w_t(n_t^s + m_t^s) + c_t^A \left(\frac{P_t}{P_t^A}\right)^{1-\theta} + T_t \\ & -q_t K_{t+1} - \frac{\gamma B_{t+1}}{P_t^A(1+R_t^B)} - \frac{D_t}{P_t^A} - w_t(n_t + m_t) - c_t = 0 \end{aligned} \tag{A.2}$$

Households must fund their consumption through wages earned on working and sales of their own production good, in which they have a degree of market power, designated by θ. They also receive income from net sales of financial assets (which consist of the fraction γ of bonds purchased from the government and deposits) and net sales of physical assets (capital). Although the aggregated level of capital is fixed within the model, individual households can buy or sell between each other, affecting the price of capital q_t. As a producer, the household also pays wages on the hours of work it employs. T_t refers to a net transfer. We assume government spending on anything other than financing debt (g_t) is zero, as in Goodfriend and McCallum (2007).

Sales equals net production constraint[26]

[26] Households consume c_t which is a basket of different goods produced by intermediate producers (indexed by i $\in$ [0,1]). An optimal demand of intermediate goods $y(i)$ is derived by maximizing the bundle given the expenditure

$$max_{y(i)} \left[\int_0^1 y_t(i)^{\frac{\theta-1}{\theta}} di\right]^{\frac{\theta}{\theta-1}}$$

subject to

$$\int_0^1 P_t(i) y_t(i) di = Z_t$$

This yields the set of demand functions. The relative demand for intermediate good i is therefore

$$y_t(i) = \left(\frac{P_t(i)}{P_t^A}\right)^{-\theta} y_t^A,$$

with θ being the elasticity of substitution between goods. With $\theta \to \infty$ there is perfect competition.

$$K_t^{\eta}(A1_t n_t)^{1-\eta} - c_t^A \left(\frac{P_t}{P_t^A}\right)^{-\theta} = 0 \tag{A.3}$$

Government budget constraint

$$T_t = g_t - tax_t = \frac{B_t}{P_t^A(1+R_{t-1}^B)} - \frac{B_{t-1}}{P_t^A} \tag{A.4}$$

The government can increase its spending g_t with discretionary policy such that net transfers, T_t, arise. The government can finance its deficit by issuing additional one period bonds, B_t, in the current period.

Deposit in advance constraint

$$c_t = v_t \frac{D_t}{P_t^A} \tag{A.5}$$

Loans

$$L_t = D_t(1 - rr_t) \tag{A.6}$$

Reserve/Deposit Ratio

$$rr_t = \frac{r_t}{D_t} \tag{A.7}$$

Loan production function

$$\frac{L_t}{P_t^A} = F\left(\frac{\gamma B_{t+1}}{P_t^A(1+R_t^B)} + A3_t k q_t K_{t+1}\right)^{\alpha} (A2_t m_t)^{1-\alpha} \tag{A.8}$$

Substitute LPF into CIA

$$c_t = v_t \frac{F\left(\frac{\gamma B_{t+1}}{P_t^A(1+R_t^B)} + A3_t k q_t K_{t+1}\right)^{\alpha} (A2_t m_t)^{1-\alpha}}{1 - rr_t} \tag{A.9}$$

Bank's Problem

$$\max \Pi_t = R_t^L L_t - R_t^D D_t + R_t r_t - w_t m_t, \tag{A.10}$$

A.2 First order conditions

Here we use our initital equations to form the Lagrangian function in which λ is the Lagrangian coefficient of the household's budget constraint, ξ is the Lagrangian coefficient of the sales equals net production constraint and the deposit in advance (DIA) constraint is substituted in. From this we derive the following first order conditions:

Derivative wrt m_t^s and n_t^s

$$-\frac{(1-\phi_t)}{1-n_t^s-m_t^s}+w_t\lambda_t=0 \tag{A.11}$$

Derivative wrt m_t

$$\frac{\phi_t}{c_t}\frac{\partial c_t}{\partial m_t}-\lambda_t w_t-\lambda_t\frac{\partial c_t}{\partial m_t}=0$$

Through our substituted DIA constraint we find

$$\frac{\partial c_t}{\partial m_t}=\frac{1-\alpha}{m_t}c_t$$

Thus

$$w_t=\left(\frac{\phi_t}{\lambda_t c_t}-1\right)\frac{1-\alpha}{m_t}c_t \tag{A.12}$$

Derivative wrt n_t

$$\xi_t A1_t(1-\eta)\left(\frac{K_t}{n_t A1_t}\right)^{\eta}-\lambda_t w_t=0$$

Thus

$$w_t=\frac{\xi_t}{\lambda_t}A1_t(1-\eta)\left(\frac{K_t}{n_t A1_t}\right)^{\eta} \tag{A.13}$$

Derivative wrt to K_{t+1}

$$\frac{\phi_t}{c_t}\frac{\partial c_t}{\partial K_{t+1}}+E_t\lambda_{t+1}q_{t+1}(1-\delta)\beta-q_t\lambda_t-\lambda_t\frac{\partial c_t}{\partial K_{t+1}}+E_t\xi_{t+1}\beta\eta K_t^{\eta-1}(A1_t n_t)^{1-\eta}$$

Through our substituted DIA constraint

$$\frac{\partial c_t}{\partial K_{t+1}}=\frac{c_t\alpha A3_t k q_t}{\frac{\gamma B_{t+1}}{P_t^A(1+R_t^B)}+A3_t k q_t K_{t+1}}$$

If we set Ω_t to

$$\Omega_t=\frac{c_t\alpha}{\frac{\gamma B_{t+1}}{P_t^A(1+R_t^B)}+A3_t k q_t K_{t+1}}$$

Then

$$\frac{\partial c_t}{\partial K_{t+1}}=\Omega_t A3_t k q_t$$

So our derivative wrt to K_{t+1} becomes

$$\left(\frac{\phi_t}{\lambda_t c_t}-1\right)\Omega_t A3_t k q_t+E_t\frac{\lambda_{t+1}}{\lambda_t}q_{t+1}(1-\delta)\beta-q_t+E_t\beta\eta\left[\frac{\lambda_{t+1}}{\lambda_t}\frac{\xi_{t+1}}{\lambda_{t+1}}\left(\frac{A1_t n_t}{K_t}\right)^{1-\eta}\right] \tag{A.14}$$

Derivative wrt to P_t

$$\lambda_t(1-\theta)c_t^A\left(P_t^A\right)^{-(1-\theta)}(P_t)^{-\theta}+\xi_t\theta c_t^A\left(P_t^A\right)(P_t)^{-\theta-1}=0$$

Rearranging gives

$$\frac{\xi_t}{\lambda_t}=\frac{\theta-1}{\theta}\frac{P_t}{P_t^A} \tag{A.15}$$

Derivative wrt B_{t+1}

$$\frac{\phi_t}{c_t}\frac{\partial c_t}{\partial B_{t+1}}+\beta\lambda_{t+1}(1+R_t^B)\frac{\gamma}{P_{t+1}^A(1+R_t^B)}-\lambda_t\frac{\gamma}{P_t^A(1+R_t^B)}-\lambda_t\frac{\partial c_t}{\partial B_{t+1}}=0$$

$$\frac{\partial c_t}{\partial B_{t+1}}=\Omega_t\frac{\gamma}{P_t^A(1+R_t^B)}$$

So our derivative wrt B_{t+1} can be written

$$\left(\frac{\phi_t}{\lambda_t c_t}-1\right)\Omega_t\frac{1}{(1+R_t^B)}+\beta\frac{\lambda_{t+1}}{\lambda_t}\frac{P_t^A}{P_{t+1}^A}\frac{1}{(1+R_t^B)}(1+R_t^B)=\frac{1}{(1+R_t^B)}$$

or

$$\left[\left(\frac{\phi_t}{\lambda_t c_t}-1\right)\Omega_t-1+\beta\frac{\lambda_{t+1}}{\lambda_t}\frac{P_t^A}{P_{t+1}^A}(1+R_t^B)\right]=0 \tag{A.16}$$

A.3 Interest rates

Riskless Rate

To derive this rate we assume the existence of a perfectly riskless asset which offers the purchaser no benefits in terms of use as collateral. If we differentiate our household's problem with respect to consumption we get

$$\frac{\partial U}{\partial c_t} = \frac{\phi_t}{c_t} - \lambda_t = \left(\frac{\phi_t}{\lambda_t c_t} - 1\right) = 0$$

Putting this back into equation (A.16) we find

$$1 + R_t^T = \frac{\lambda_t}{\lambda_{t+1}} \frac{P_{t+1}^A}{P_t^A} \tag{A.17}$$

Bond Rate

Using equation (A.16) we can find that

$$1 + R_t^B = 1 - \left(\frac{\phi_t}{\lambda_t c_t} - 1\right) \Omega_t \frac{\lambda_t}{\lambda_t + 1} \frac{P_{t+1}^A}{P_t^A}$$

and that

$$\frac{1 + R_t^B}{1 + R_t^T} = 1 - \left(\frac{\phi_t}{\lambda_t c_t} - 1\right) \Omega_t$$

We can interpret $\left(\frac{\phi_t}{\lambda_t c_t} - 1\right) \Omega_t$ as a premium yield paid on bonds for the liquidity service they provide, or liquidity premium. We denote this LP_t and can write it as:

$$R_t^T - R_t^B = LP_t \tag{A.18}$$

This premium depends on the marginal value of collateral.

The liquidity service on capital (physical assets) can be written:

$$LSK = kLP$$

where k denotes the extent to which capital is inferior to bonds as a form of collateral. Together the liquidity service on bonds and the liquidity service on capital make up the overall liquidity service of collateral and thus the return on collateralised loans. This means:

$$R_t^L - R_t^B = LSK = \left(\frac{\phi_t}{\lambda_t c_t} - 1\right) k\Omega_t \tag{A.19}$$

Interbank/Policy rate

In our full model the interbank rate is set by the policy-maker via a policy rule in response to changes in output and inflation. However it is worth looking at how this rate also relates to the other interest rates in the model.

$$R_t^T - R_t = \frac{v_t m_t w_t}{(1-\alpha)(1-rr_t)c_t} \tag{A.20}$$

Marginal product of loans per unit of labour equals marginal cost. Thus, the difference between policy and riskless rates is the real marginal cost of loan management. This gives the collateralised external finance premium (EFP).

Uncollateralsed Loan rate

$$\frac{\partial \Pi_t}{\partial m_t} = R_t^L - R_t - w_t / \frac{\partial L_t/P_t}{\partial m_t} = 0$$

Given

$$\frac{\partial L_t/P_t}{\partial m_t} = m_t^{-1}(1-\alpha)L_t/P_t$$

by the Deposit in Advance Constraint we have

$$R_t^L - R_t = \frac{v w_t m_t}{(1-\alpha)(1-rr_t)c_t}.$$

Collateralsed Loan rate

Multiply by the factor share of monitoring in loan production $(1-\alpha)$ to give the collateralised EFP.

$$R_t^L - R_t = \frac{v_t m_t w_t}{(1-rr_t)c_t} \tag{A.21}$$

Deposit rate

$$R_t^D = R_t(1-rr_t) \tag{A.22}$$

A.4 Steady-states

Now we must identify each of our variables in the steady state. We assume no inflation so $P = P^A = 1$. We also assume a trend growth rate of our productivity and monitoring shocks of $(1+\varpi)$ so $A1 = A2 = (1+\varpi)$ and thus λ shrinks at the rate ϖ and $\frac{\lambda_{t+1}}{\lambda_t} = \frac{1}{1+\varpi}$. K is constant and $q = 1$ in the steady state. We set or reserve deposit ratio to 0.1 in the steady state.

This means we require one identifying equation per variable.

Lagrangian

$$\lambda = \frac{1-\phi}{w(1-n-m)} \tag{A.23}$$

Monitoring work

$$m = \left(\frac{\phi}{\lambda c} - 1\right)\frac{1-\alpha}{w}c \tag{A.24}$$

Wages

$$w = \frac{\theta-1}{\theta}(1-\eta)\left(\frac{K}{n}\right)^{\eta} \tag{A.25}$$

Employment in the real sector

$$\left(\frac{\phi}{\lambda c} - 1\right)\Omega kq + \frac{1}{1+\gamma}q(1-\delta)\beta - q + E_t\beta\eta\left[\frac{1}{1+\gamma}\frac{\xi}{\lambda}\left(\frac{n}{K}\right)^{1-\eta}\right] = 0$$

or

$$\left(\frac{\phi}{\lambda c} - 1\right)\Omega kq - 1 + \frac{\beta}{1+\gamma}\left[(1-\delta) + \eta\frac{\theta-1}{\theta}\left(\frac{n}{K}\right)^{1-\eta}\right] = 0 \tag{A.26}$$

Capital

$$c = K^{\eta}n^{1-\eta} - \delta K \tag{A.27}$$

Consumption

$$c = \frac{vF}{1-rr}(b+kqK)^{\alpha}(m)^{1-\alpha} \tag{A.28}$$

Deposits

$$D = \frac{c}{v} \tag{A.29}$$

Reserves

$$r = rrD = \frac{c}{v}rr \tag{A.30}$$

Total bond holdings

$$B = 0.35c \tag{A.31}$$

Loans

$$L = D(1-rr) \tag{A.32}$$

Omega

$$\Omega = \frac{c\alpha}{b^p + kqK} \tag{A.33}$$

Price of bonds

$$P^B = \frac{1}{(1 + R^B)} \tag{A.34}$$

Real value of bonds

$$b = \frac{B}{1 + R^B} \tag{A.35}$$

Liquidity shortfall

$$\tau = R^L - R^{IB} \tag{A.36}$$

Government budget constraint

$$T = b - b(1 + R^B) \tag{A.37}$$

Liquidity premium

$$LP = \left(\frac{\phi}{\lambda c} - 1\right)\Omega \tag{A.38}$$

EFP

$$EFP = \frac{vmw}{(1-\alpha)(1-rr)c} \tag{A.39}$$

Collateralised EFP

$$CEFP = \frac{vmw}{(1-rr)c} \tag{A.40}$$

Riskless rate

$$R^T = \gamma \tag{A.41}$$

Bond rate

$$R^B = R^T - LP \tag{A.42}$$

Policy rate

$$R = R^T - EFP \tag{A.43}$$

Lending rate

$$R^L = R + CEFP \tag{A.44}$$

Deposit rate

$$R^D = R(1 - rr) \tag{A.45}$$

From these equations and our exogenously determined parameters α, β, γ, δ, η, θ, ϕ, k, and v we have a fully determined model and can derive the steady state values for each of our variables (see Table 6). From this we can also carry out steady state analysis of our system via comparative statics.

A.5 The Log-linearised model

The following system of 25 equations defines our benchmark model which contains 27 variables, four lags and eight exogenous shock terms. These equations, plus an identifying equation for each lagged term, are solved using the King and Watson (1998) algorithm.

Supply of labour

$$\frac{n}{(1-n-m)}\widehat{n}_t + \frac{m}{(1-n-m)}\widehat{m}_t - \widehat{\lambda}_t - \widehat{w}_t = 0 \tag{A.46}$$

Demand for labour

$$\widehat{m}_t + \widehat{w}_t + \frac{(1-\alpha)c}{mw}\left(\widehat{c}_t + \frac{\phi_t}{\lambda}\widehat{\lambda}_t\right) = 0 \tag{A.47}$$

DIA constraint

$$\widehat{c}_t + \widehat{p}_t = \widehat{D}_t + \widehat{v}_t \tag{A.48}$$

Supply of banking services:

$$\begin{aligned}\widehat{c}_t &= \widehat{v}_t c + \widehat{rr}_t c + (1-\alpha)(a2_t + \widehat{m}_t) + \\ &\alpha\left[\frac{b\gamma}{b+(1+\varpi)kK}\widehat{b}_{t+1} + \frac{kK(1+\varpi)}{b+(1+\varpi)kK}(a3_t + \widehat{q}_t)\right]\end{aligned} \tag{A.49}$$

Aggregate supply:

$$\widehat{c}_t = (1-\eta)\left(1+\frac{\delta K}{c}\right)(a1_t + \widehat{n}_t) - \frac{\delta K}{c}\hat{q}_t \tag{A.50}$$

Marginal cost:

$$\widehat{mc}_t = \widehat{n}_t + \widehat{w}_t - \widehat{c}_t \tag{A.51}$$

Mark-up

$$\widehat{mc}_t = \widehat{\xi}_t - \widehat{\lambda}_t \tag{A.52}$$

Inflation:

$$\widehat{\pi}_t = \widehat{p}_t - \widehat{p}_{t-1} \tag{A.53}$$

Calvo pricing:

$$\widehat{\pi}_t = \kappa\widehat{mc}_t + \beta E_t\widehat{\pi}_{t+1} + a5_t \tag{A.54}$$

Marginal value of collateralised lending:

$$\Omega_t = \frac{kK}{b+kK}(\hat{c}_t - \hat{q}_t - a3_t) - \frac{\gamma b}{b+kK}\hat{b}_{t+1} \tag{A.55}$$

Asset Pricing:[27]

$$\widehat{q}_t \left[1 - k\Omega\left(\frac{\phi_t}{c\lambda} - 1\right)\right] = \left[\frac{\beta(1-\delta)}{1+\varpi} + \frac{\beta\eta mc}{1+\varpi}\left(\frac{n}{K}\right)^{1-\eta}\right]\left(E_t\widehat{\lambda}_{t+1} - \widehat{\lambda}_t\right) \tag{A.56}$$
$$+\frac{\beta(1-\delta)}{1+\varpi}E_t\widehat{q}_{t+1} + \frac{k\Omega\phi_t}{c\lambda}\left(-\widehat{c}_t - \widehat{\lambda}_t\right)$$
$$+k\Omega\left(\frac{\phi_t}{c\lambda} - 1\right)\left(\widehat{\Omega}_t + a3_t\right)$$
$$+\left(\frac{\beta\eta mc}{1+\varpi}(\frac{n}{K})^{1-\eta}\right)E_t\left[\widehat{mc}_{t+1} + (1-\eta)\left(\widehat{n}_{t+1} + a1_{t+1}\right)\right]$$

Government budget constraint:

$$T\widehat{T}_t = b\left[\widehat{b}_t - \widehat{b}_{t-1} - R^B\left(\widehat{b}_{t-1} + \widehat{R}^B_{t-1}\right)\right] \tag{A.57}$$

Bond holding:

$$\widehat{B}_t = a6_t \tag{A.58}$$

Riskless interest rate:

$$\widehat{R}^T_t = \widehat{\lambda}_t + E_t\widehat{\pi}_{t+1} - E_t\widehat{\lambda}_{t+1} \tag{A.59}$$

Liquidity service on bonds:

$$R^T\widehat{R}^T_t - R^B\widehat{R}^B_t = \left(\frac{\phi_t}{c\lambda} - 1\right)\Omega\widehat{\Omega}_t - \frac{\phi\Omega}{c\lambda}(\widehat{c}_t + \widehat{\lambda}_t) \tag{A.60}$$

External finance premium:

$$\widehat{EFP}_t = \widehat{v}_t + \widehat{w}_t + \widehat{m}_t - \widehat{c}_t + \widehat{rr}_t \tag{A.61}$$

Other interest rates:

$$\widehat{R}_t = \widehat{R}^T_t - \widehat{EFP}_t \tag{A.62}$$

$$\widehat{R}^L_t = \widehat{R}_t + \widehat{EFP}_t \tag{A.63}$$

$$\widehat{R}^D_t = \widehat{R}_t - \widehat{rr}_t\frac{rr}{(1-rr)} \tag{A.64}$$

Policy feedback rule:

$$\widehat{R}_t = (1-\rho)\left(\phi_\pi\widehat{\pi}_t + \phi_y\widehat{y}_t\right) + \rho\widehat{R}_{t-1} + a4_t \text{ for } R_t > 0 \tag{A.65}$$

Reserves:

$$\widehat{r}_t = \rho_r\widehat{r}_{t-1} + (-\psi_y)(1-\rho_r)\widehat{y}_t + (-\psi_\pi)(1-\rho_r)\widehat{\pi}_t \text{ for } R_t = 0 \tag{A.66}$$

[27]Note that in steady-state $\frac{\xi}{\lambda} = mc$ and $\frac{\lambda_{t+1}}{\lambda_t} = \frac{1}{1+\varpi}$.

Velocity:

$$\widehat{v}_t = a7_t \tag{A.67}$$

Loans:

$$\widehat{L}_t = \frac{1}{1-rr}\widehat{D}_t - \frac{rr}{1-rr}\widehat{r}_t \tag{A.68}$$

Reserve deposit ratio:

$$\widehat{rr}_t = \widehat{r}_t - \widehat{D}_t \tag{A.69}$$

Acknowledgements

The views expressed in this article are solely those of the authors and do not necessarily reflect the views of the European Central Bank, the Eurosystem or the Bank of England. Acknowledgements: A version of this paper was presented at the Royal Economic Society Annual Conference, National Institute of Economic and Social Research (NIESR) Brown Bag seminar, the Bank of England, the Narodowy Bank Polski, European Area Business Cycle Network, and the Covid-19 Economic Recovery Seminar in Whitehall. We thank participants for many helpful comments.

Jagjit S. Chadha
National Institute of Economic and Social Research (NIESR), London, United Kingdom; email: J.Chadha@niesr.ac.uk

Luisa Corrado
University of Rome Tor Vergata, Rome, Italy; email: luisa.corrado@uniroma2.it

Jack Meaning
Bank of England, London, United Kingdom; email: jack.meaning@bankofengland.co.uk

Tobias Schuler
European Central Bank, Frankfurt am Main, Germany; email: tobias.schuler@ecb.europa.eu

PDF ISBN 978-92-899-4811-1 ISSN 1725-2806 doi:10.2866/165912 QB-AR-21-079-EN-N