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Should Unconventional Monetary Policies Become Conventional?

by Dominic Quint and Pau Rabanal

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Abstract

The large recession that followed the Global Financial Crisis of 2008-09 triggered unprecedented monetary policy easing around the world. Most central banks in advanced economies deployed new instruments to affect credit conditions and to provide liquidity at a large scale after short-term policy rates reached their effective lower bound. In this paper, we study if this new set of tools, commonly labeled as unconventional monetary policies (UMP), should still be used when economic conditions and interest rates normalize. In particular, we study the optimality of asset purchase programs by using an estimated non-linear DSGE model with a banking sector and long-term private and public debt for the United States. We find that the benefits of using such UMP in normal times are substantial, equivalent to 1.45 percent of consumption. However, the benefits from using UMP are shock-dependent and mostly arise when the economy is hit by financial shocks. When more traditional business cycle shocks (such as supply and demand shocks) hit the economy, the benefits of using UMP are negligible or zero.

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"In pre-crisis days, policymakers assumed that tweaking short-term interest rates was enough to influence all important financial decision-making. This was wishful thinking, based on a couple of decades of atypical US experience. Other economies still needed extra policy instruments, as has the US since the crisis."

Adam Posen, Financial Times, August 23, 2016

"The long-term interest rate is a central variable in the macroeconomy. It matters to borrowers looking to start a business or purchase a home; to lenders weighing the risks and rewards of extending credit; to savers preparing for college or retirement; and to policymakers gauging the state of the economy and financing government expenditure."

US Council of Economic Advisers, Report on "Long-Term Interest Rates: A Survey", July 2015

1 Introduction

The economic fallout from the Global Financial Crisis in 2008–09 triggered unprecedented monetary policy easing around the world. Initially, central banks responded aggressively by decreasing interest rates until reaching their effective lower bound. Afterwards, central banks in most advanced economies started deploying a new set of instruments to provide liquidity and affect credit conditions at a large scale. These interventions, that became commonly known as *unconventional monetary policy*, were introduced via large scale asset purchase programs of domestic assets (including government bonds, mortgage backed securities, and private sector debt) as well as liquidity provision and refinancing operations with commercial banks.[1] As a result of such unconventional policies, central bank balance sheets expanded to unprecedented levels. For instance, the Federal Reserve's balance sheet fluctuated at about 5.5 percent of annual GDP on average between 1955-2007, but it more than quadrupled since then to 23.7 percent of GDP in 2016. For other major central banks, the same ratio evolved as follows: in the UK, the ratio went from 6.5 percent on average between 1955-2007 to 22.5 percent in 2015. In the Euro Area, the ratio went from 13 percent in 2006, to 34.1 percent in 2016. In Japan, this ratio went from 10 percent in 1994, to 21 percent right before the crisis in 2007, and to 88.7 percent in 2016.

[1] Lenza *et al.* (2010) provide an overview of the different actions taken by the Fed, the Bank of England and the ECB in response to the crisis. Gagnon *et al.* (2011) compare the policy steps taken by the Fed with the ones taken by Bank of Japan and the Bank of England. Fratzscher *et al.* (2016) study the international spillovers of the main actions taken by the ECB in response to the crisis.

During the crisis, and especially after the collapse of Lehman Brothers, corporate lending spreads increased to levels only comparable to the Great Depression, and borrowers saw their access to credit deteriorate (see e.g. Ivashina and Scharfstein, 2010). By adopting unconventional policy instruments, policymakers pursued broadly two goals. First, as short-term interest rates quickly reached their lower bound, central banks needed to use other tools to provide further monetary policy accommodation to affect spreads between short-term and long-term rates directly. Second, with the provision of liquidity at a large scale, central banks aimed at restoring the functioning of credit and financial markets, and the transmission mechanism of monetary policy that had become impaired.

In this paper, we study if the unconventional tools deployed during the crisis in the form of asset purchase programs should become conventional and still be used after the economy and interest rates return to more normal conditions. We focus on whether monetary policy should target both the short-term rate and the spread between long- and short-term rates when the zero lower bound is not binding. In this sense, we will offer guidance on the question whether central banks should aim at phasing out their new measures introduced during the recent crisis or whether there are benefits in adding asset purchase programs to their standard policy toolkit.[2] Prior to the crisis, the prevailing consensus was that an expansion of the monetary base was regarded as having no effect on real variables (e.g. Wallace, 1981; Eggertsson and Woodford, 2003). Instead, the prevailing view was that central banks should focus on communicating the path of the short-term interest rate (e.g. via a transparent policy function) and allow monetary policy to be transmitted along the yield curve of government bonds as well as across private financial asset classes, including bank loans. This transmission mechanism crucially depends on the assumption of efficient financial markets (in the spirit of Fama, 1970). However, in the presence of market segmentation, the perfect substitutability between different financial assets breaks down, and policy makers can affect yields above and beyond targeting the short-term interest rate.

One advantage of making these unconventional measures conventional would be that central

[2]The Federal Reserve increased rates for the first time in almost a decade on December 16, 2015. The FOMC statement indicated that the Fed would keep the size of its balance sheet unchanged: "The Committee is maintaining its existing policy of reinvesting principal payments from its holdings of agency debt and agency mortgage-backed securities in agency mortgage-backed securities and of rolling over maturing Treasury securities at auction, and it anticipates doing so until normalization of the level of the federal funds rate is well under way. This policy, by keeping the Committee's holdings of longer-term securities at sizable levels, should help maintain accommodative financial conditions." This policy has been reiterated in all FOMC statements during 2016.

banks could avoid the well known "Greenspan conundrum" (Greenspan, 2005). Conventional monetary policy affects the short-term rate, but it might not be able to affect long-term rates with the same precision because of time-varying term and risk premia. Longer term rates have stronger macroeconomic effects, as our quote from the US Council of Economic Advisers above suggests (see also Thornton, 2012). On the other hand, unconventional measures might be associated with welfare costs when affecting the slope of the yield curve away from its market-driven equilibrium value. In addition, there might be other costs such as smaller revenues by the fiscal authority if the central bank incurs in losses (e.g. Hall and Reis (2015) and Del Negro and Sims (2015)). Unconventional monetary policies might also imply less efficient credit intermediation if the central bank either lends to the private sector directly or chooses which sectors should receive more credit. Furthermore, since the history of unconventional policy measures shows diminishing returns (e.g. Krishnamurthy and Vissing-Jorgensen, 2011), unconventional policy might only be effective when the economy is hit by large financial shocks or when conducted at a larger scale than is politically feasible.

To answer these questions, we rely on a general equilibrium model based on Justiniano *et al.* (2013), which is augmented with a banking sector as in Gertler and Karadi (2013) and Andreasen *et al.* (2013). In the model, banks channel funds from households to non-financial firms and the government. Banks raise short-term deposits, provide long-term financing to firms and purchase long-term government bonds, thereby facilitating maturity transformation. Long-term private loans result from the assumption that debtors engage in lumpy investment activities and cannot re-negotiate their debt every period.[3] Given this friction, the return on private assets as well as on government papers becomes sticky and agents are forward-looking when negotiating these contracts. Our assumptions relating to long-term debt reflect the fact that the majority of outstanding bonds in the US are fixed rate notes. Only around 2 percent of US Treasuries have a variable coupon and around 90 percent of US corporate bonds are issued as fixed rate bonds.

The model is estimated by taking a second-order approximation to the equilibrium conditions, and by using a Generalized Method of Moments (GMM) procedure to match sixty-three relevant first and second order moments from nine macroeconomic and financial time series. The estimated coefficients are obtained to match the data when the model is simulated up to second order. This is

[3]In the model, firms obtain financing with bank loans, but the financial contract could also be thought of as a perpetual bond with an embedded option, which allows the firm to redeem the bond when it re-optimizes its capital level. For this reason, we use the terms private sector bonds and private sector loans interchangeably in the paper.

important because it allows to account for precautionary savings motives, and also because we rely on the same second-order approximation to the equilibrium conditions for welfare evaluation purposes. In the model, conventional monetary policy affects the short-term deposit rate, while unconventional monetary policy encompasses policies targeting the long-term corporate or government bond spreads over the short-term deposit rate. In our model, we only focus on asset purchase programs, and the central bank can conduct these by purchasing either private or government sector debt. When the central bank provides financing to the private sectior, it basically crowds out intermediation by financial intermediaries. Since these banks are leverage constrained—in contrast to the central bank—such a policy is not neutral in affecting spreads and is especially effective when financial shocks, such as shocks to bank capital, hit the economy. By buying government bonds, policy makers can also affect total demand for private securities. These purchases increase banking sector liquidity and lower yields of government bonds. This leads financial intermediaries to rebalance their portfolio into private securities, thereby reducing corporate spreads and stimulating investment. This is the channel central banks have in mind when engaging in Quantitative Easing (QE) measures by purchasing government bonds.

The main results are as follows. Under an estimated Taylor rule, welfare gains from using Unconventional Monetary Policies (UMP) can be up to 1.45 percent of steady-state consumption. In particular, UMP is mostly useful to react to financial shocks, which generally affect bank capital, private sector spreads, investment, and employment. UMP does not help much with normal "business cycle" supply and demand shocks. In this category we include TFP and investment-specific technology shocks, mark-up shocks to price and wage settting, preference shocks to consumption and labor supply, and government spending shocks. In this paper, we do not attempt to model or quantify the costs of UMP, which might include interactions with the fiscal authority if the central bank incurs in losses, and less efficient credit intermediation by the central bank. Because of the benefits of UMP are small under standard business cycle shocks, they are likely to be offset by these costs. In terms of the modality of UMP, we find that providing direct credit to firms or purchasing government bonds delivers a very similar result. Similar welfare gains from UMP arise when the central bank runs a strict inflation targeting regime, but these benefits are much lower when the central bank follows an optimized Taylor rule that targets price and wage inflation.

Our paper complements the recent theoretical literature that evaluates the UMP measures implemented by central banks during the Global Financial Crisis. These studies differ mainly in the way the perfect substitutability between different financial assets at different maturities is broken down, and thus, how UMP is transmitted to the real economy. Chen *et al.* (2012) assume that bonds with different maturities are imperfect substitutes and households are willing to pay a premium on bonds of their preferred maturities. In their model, the financial friction is at the household level, with some households having a preference for saving with long-term instruments. The transmission channel of UMP in such a framework is very similar to the one of conventional monetary policy. By purchasing assets with an appropriate maturity and altering the return that households earn on these assets, UMP is transmitted by also affecting the consumption-saving decision of households. Chen *et al.* (2012) find only weak evidence of this transmission channel and therefore negligible effects of UMP on the real economy in the US. Del Negro *et al.* (2016) focus on the illiquidity of certain assets classes. They assume that, in a crisis, private assets become illiquid compared to government bonds, which gives rise to a premium between these two asset classes. By buying private assets in exchange for liquid assets, the central bank mitigates this effect and helps to counter the decline of investment funding. Calibrated to match liquidity premia during the crisis, Del Negro *et al.* (2016) show that shocks to the market liquidity of assets can explain a large share of the recession in the US and that the policy response by the Fed played an important role in attenuating the macroeconomic impact of these shocks.

Another stand of the literature focuses on the role of frictions in the intermediation between savers and borrowers (Gertler and Kiyotaki, 2010, Gertler and Karadi, 2011, and Cúrdia and Woodford, 2011). Direct lending by the central bank (or targeted asset purchases) can mitigate disruption in the intermediation of funds and therefore becomes desirable when these frictions are non-trivial. In such a framework, the transmission channels of conventional policy and UMP are very different. While the former targets the return earned by savers, the latter is able to directly target the credit costs of borrowers and therefore their investment decision. Gertler and Karadi (2013) extend the framework by incorporating government bonds as (imperfect) substitutes for private securities. In their model, purchases of government bonds will incentivize investors to rebalance their portfolio into private securities due to the arbitrage relation between the return on private assets and government papers. This is a feature that we also incorporate in our model.

The papers listed above focus on the evaluation of the policies implemented during the Global Financial Crisis when the zero (or effective) lower bound became a binding constraint for monetary policy. Therefore, they offer little guidance on the question regarding whether theses instruments should be added to the standard policy toolkit when conventional monetary policy is also available. Two exceptions are the works by Ellison and Tischbirek (2014) and Carlstrom *et al.* (2016) which are the closest to our analysis. In particular, Ellison and Tischbirek (2014), who build on a similar framework as Chen *et al.* (2012), find that central banks should coordinate conventional policy and UMP as follows: the former should respond to inflation while the latter should offset output gap fluctuations. Our paper contributes to this debate by using a micro-founded welfare criterion, in contrast to Ellison and Tischbirek (2014), who use a simple, non-microfounded, loss function. In addition, we focus on UMP rules that target credit spreads, which better corresponds to what central banks were focusing on during and after the crisis. Carlstrom *et al.* (2016) study the role of the banking sector in intermediating funds from households to non-financial firms and emphasize the usefulness of UMP measures to counteract shocks that are rooted in the financial sector, as we do in the present paper. However, unlike Carlstrom *et al.* (2016), we implement long-term credit contracts and a maturity-transformation motive for banks, and we estimate our model non-linearly, which allows us to fully account for precautionary motives effects.[4]

The rest of the paper is organized as follows. Section 2 describes the key features of our structural model. Section 3 and 4 presents the econometric methodology we use to estimate the parameters of the model and the model fit. We introduce unconventional monetary policy and explain its transmission into the real economy in section 5. Section 6 describes the welfare maximizing policy, while section 7 draws some concluding remarks.

2 The Model

Our framework is based on Justiniano *et al.* (2013), which is a standard New Keynesian model, with nominal and real rigidities and several shocks.[5] We modify their framework to include a banking sector as in Gertler and Karadi (2013) and a production sector with lumpy investment as in Andreasen *et al.* (2013). Banks channel funds from households to non-financial firms and the government. Due to an agency problem between bankers and depositors, banks cannot exclusively rely on external financing, which gives rise to a financial accelerator mechanism. In the production sector, we assume that firms can only infrequently adjust their capital stock and negotiate the

[4] An early contribution by McGough *et al.* (2005) examines if the central bank should target long-term rates by using conventional monetary policy only.

[5] See also the contributions by Smets and Wouters (2003, 2007).

refinancing of their investment, as in Sveen and Weinke (2007). As a result, firms issue long-term debt, and the nominal lending rate is constant over the life of the loan. A similar structure applies to government bonds. Therefore, the main difference with respect to Gertler and Karadi (2013) is the presence of long-term debt: in our model, banks facilitate maturity transformation.[6]

The model includes households (consisting of workers and bankers), intermediate goods producers, retailers, final goods producers, capital goods producers, financial intermediaries, the central bank and the fiscal authority. In what follows, we present a summary of the model and only elaborate on the main differences between our model and the framework found in Justiniano *et al.* (2013). For this reason, we start by describing the problem of intermediate goods producers, capital goods producers and financial intermediaries. Then, we briefly describe the remaining agents in the economy, which are standard in this literature. An online appendix includes all the details of the model and a derivation of all equilibrium conditions.[7]

2.1 Non-Financial Firms

There are four types of firms operating in the production sector. First, intermediate goods producers hire labor and purchase capital to produce a homogeneous good. These firms face a Calvo (1983)-type restriction when they upgrade their capital stock, which captures the idea that investment expenditures are lumpy (see Reiter *et al.*, 2013). Second, retailers purchase these homogeneous goods and turn them into differentiated goods. Retailers operate under monopolistic competition and charge a mark-up over their marginal costs, i.e. over the price of the intermediate good. The market power of retailers and the associated mark-up is time-varying. We deviate from Justiniano *et al.* (2013) and follow the Rotemberg (1982) quadratic cost model to implement sticky retail prices.[8] We assume that retail prices are partially indexed to a combination of steady-state and lagged inflation. Third, final good producers purchase differentiated goods and turn them into final goods that are used for consumption, investment and government spending. Finally, capital-

[6]Gertler and Karadi (2013) also introduce long-term bonds in their model, but they implement them as perpetuities using a short-cut proposed by Woodford (2001). But the aggregate capital stock is refinanced every period. In our model, only a fraction of the capital stock is refinanced every period, which adds realism and also limits the extent to which unconventional monetary policies affect the real economy.

[7]The appendix is available at www.paurabanal.net/research.html

[8]This is mostly for practical reasons, as we will solve our model using a second-order perturbation methods. Implementing price stickiness à la Calvo (1983) together with time-varying mark-ups does not allow to write the optimal price setting equations recursively. This is not an issue when the model is log-linearized, as in Justiniano *et al.* (2013).

producing firms purchase final goods to invest in capital goods that are sold to intermediate goods producers. Creating capital goods is subject to flow adjustment costs. In what follows, we present the optimization problem of intermediate goods producers and capital goods producers in more details. As the retail and the final good sector are fairly standard, we refer the reader to the online appendix for further details.

2.1.1 Intermediate Goods Producers

Following Andreasen *et al.* (2013), every period only a fraction $(1-\theta_k)$ of intermediate goods producers adjust their capital stock. We denote the capital stock adjusted in the current period with $\bar{K}_t$. When adjusting to the new capital stock, intermediate goods producers purchase capital from capital good producers financed by a credit obtained from financial intermediaries. The credit contract has a fixed nominal interest rate $\bar{r}_t^L$, until intermediate goods producers receive the next Calvo signal, which will allow them to adjust the capital stock, pay off the old loan, and negotiate a new loan. Another way to think about this financial contractis that firms issue a perpetual bond with an embedded option, which allows the firm to redeem the bond when it re-optimizes its capital level. The contract signed between intermediate goods producers and capital goods producers allows the former at the end of the contract period to sell the capital stock to the latter at the original price. In addition, intermediate goods producers need to pay a fee to capital goods producers that is a constant fraction of the value of the installed capital stock, $\omega P_t^K \bar{K}_t$, with P_t^K being the price of capital. As in Andreasen *et al.* (2013), one can think of these expenditures as compensation to capital producers for providing support and maintenance on installed capital. This setup implies that physical capital exchanged between intermediate goods producers and capital producing firms is valued based on the price of capital when a contract is signed. This way, good-producing firms do not face uncertainty about the price of capital, and the interaction between intermediate good- and capital-producing firms resembles a leasing relationship.

While capital cannot be adjusted every period, producers can change the labor input $L_t^{\mathscr{D}}$ every period. We denote the Cobb-Douglas production function for intermediate goods with $Y_t^M = A_t^{(1-\alpha)} Z_t (K_{t-1})^{\alpha} (L_t^{\mathscr{D}})^{(1-\alpha)}$, where production is affected by two productivity shocks: a stationary shock (Z_t) that follows an AR(1) process in logs, and a non-stationary shock (A_t) that follows an AR(1) process in logs and first differences. The price at which intermediate goods are sold to retailers is P_t^M. Intermediate goods producers solve the following maximization problem taking into account the infrequent adjustment of the capital stock:

$$\max_{\bar{K}_t, L^{\mathscr{D}}_{t+j|t}} E_t \sum_{j=1}^{\infty} \left\{ (\theta_k)^{j-1} \beta^j \frac{\Xi_{t+j}}{\Xi_t} \left[\frac{P^M_{t+j}}{P_{t+j}} Y^M_{t+j|t} - \bar{r}^L_t \left(\prod_{i=1}^{j} \frac{P_{t+i}}{P_{t+i-1}} \right)^{-1} \frac{P^K_t}{P_t} \bar{K}_t \right. \right.$$
$$\left. \left. - \quad \omega \left(\prod_{i=1}^{j} \frac{P_{t+i}}{P_{t+i-1}} \right)^{-1} \frac{P^K_t}{P_t} \bar{K}_t - W_{t+j} L^{\mathscr{D}}_{t+j} \right] \right\}$$

where the time notation $t+j \mid t$ indicates production and labor demand at time $t+j$ given that the capital stock was adjusted at time t. We denote the consumption goods price index with P_t and real wages with W_t. Since households own firms, the stochastic discount factor $\beta^j \Xi_{t+j}/\Xi_t$ is derived from the household Euler equation with Ξ_t being the marginal utility of consumption. The optimal investment decision is described by:

$$E_t \sum_{j=1}^{\infty} \left\{ (\theta_k)^{j-1} \beta^j \frac{\Xi_{t+j}}{\Xi_t} \left[\frac{P^M_{t+j}}{P_{t+j}} \alpha \frac{Y^M_{t+j|t}}{\bar{K}_t} - \left(\prod_{i=1}^{j} \pi_{t+i} \right)^{-1} \left(\bar{r}^L_t + \omega \right) \frac{P^K_t}{P_t} \right] \right\} = 0, \tag{1}$$

where $\pi_t \equiv P_t/P_{t-1}$denotes the price inflation rate. Equation (1) links the expected marginal revenue product of capital with the expected marginal cost of maintaining and financing the capital stock. The loan and the service contract are specified in nominal terms, which implies that intermediate goods producers need to take into account expected cumulative inflation. All firms can adjust their labor demand every period and they take wages as given: firms equalize real wages with the marginal product of labor. As a result, firms' capital-labor ratios are the same, and the aggregate level of production and labor demand depend on the aggregate level of capital.

2.1.2 Capital Goods Producers

Capital goods producers sell capital to intermediate goods producers, with an agreement to repurchase it at the original price. In addition, they provide a service for the maintenance of the capital stock for which they charge a fee that is proportional to the price of capital (ωP^K_t). The duration of the contract is determined in the intermediate good sector. Capital good producers solve the following maximization problem:

$$\max E_t \sum_{j=0}^{\infty} \beta^j \frac{\Xi_{t+j}}{\Xi_t} \left(\omega \frac{V_{t+j}}{P_{t+j}} - I_{t+j} \right), \tag{2}$$

with I_t being investment spending and where the value of outstanding contracts V_t depends on capital vintages sold in previous periods:

$$\frac{V_t}{P_t} = (1-\theta_K) \sum_{j=0}^{\infty} (\theta_K)^j \frac{P^K_{t-j}}{P_t} \bar{K}_{t-j}. \tag{3}$$

The total demand for capital is given by the demand for new capital and the capital stock from last period:

$$K_t = (1-\theta_K) \bar{K}_t + \theta_K K_{t-1}, \tag{4}$$

while the law of motion for the aggregate capital stock takes into account adjustment costs $\mathcal{F}(\cdot)$ for investment:

$$K_t = (1-\delta) K_{t-1} + \xi^I_t \left[1 - \mathcal{F}\left(\frac{I_t}{I_{t-1}}\right)\right] I_t, \tag{5}$$

where ξ^I_t is an investment shock which follows an AR(1) process in logs, and $\mathcal{F}(\cdot)$ is an increasing, convex function. The equilibrium conditions are derived in the online appendix consisting of a Tobin's Q relation for net investment, together with the conditions that relate the expected marginal revenues from the maintenance service and the expected marginal cost of providing the capital stock.

2.2 Financial Intermediaries

Banks use their net worth N_t and household deposits D_t to provide financing to intermediate good producers and to purchase government bonds. Deposit accounts are kept at financial intermediaries not owned by the household so that financial intermediaries always manage other people's money. This assumption is needed to motivate the moral hazard problem that we describe below. Each period, a banker stays in office with probability θ_B. Thus, the expected professional life of a banker is $(1-\theta_B)^{-1}$, and every period a certain mass of bankers become workers (a similar mass of workers become bankers so this keeps proportions stable).

We extend Gertler and Karadi (2013) by introducing long-term private and public debt. In their framework, bankers who exit the market transfer their final period assets to the household, which in turn transfers a fraction of that amount to new bankers as "startup funds". This simple mechanism can be implemented because Gertler and Karadi (2011, 2013) have one-period loans only. With long-term debt, banks hold a loan portfolio of different maturities and hence exiting bankers need to sell this portfolio when they retire. As in Andreasen *et al.* (2013), we introduce an insurance agency financed by a proportional tax τ_B on banks' profit. When a banker retires, the role of this agency is to create a new bank with an identical asset and liability structure and effectively guarantee the outstanding contracts of the old bank. This agency therefore ensures the existence of a representative bank and that the wealth of this bank is bounded with an appropriately calibrated tax rate.

2.2.1 Corporate Long-Term Loans

The bank manages the portfolio of loans given to the private sector, which includes all loans given at a nominal amount $P^K_{t-j}\bar{K}_{t-j}$ and which pay a gross interest rate of $\bar{R}^L_{t-j}$ for each period $j = 0, 1, ...$ We will define the gross interest rate as $\bar{R}^L_t \equiv 1 + \bar{r}^L_t$. Aggregate real lending to the private sector len_t, which takes into account that loans mature with probability θ_k, can be recursively written as:

$$len_t = (1-\theta_k)\sum_{j=0}^{\infty}(\theta_k)^j \frac{P^K_{t-j}}{P_t}\bar{K}_{t-j}, \tag{6}$$

and the total real revenues, rev_t, earned on the portfolio are given by:

$$rev_t = (1-\theta_k)\sum_{j=0}^{\infty}(\theta_k)^j \bar{R}^L_{t-j}\frac{P^K_{t-j}}{P_t}\bar{K}_{t-j}. \tag{7}$$

We define the average return on the private sector loan portfolio by $R^L_t \equiv \frac{rev_t}{len_t}$, which is a weighted average of current and past long-term loan interest rates.

2.2.2 Long-Term Government Bonds

We introduce long-term government debt in a similar way than private sector debt. Each period, the government issues new debt B^N_t with a gross interest rate $\bar{R}^G_t$. Once the security is issued, it pays the net interest rate $\bar{r}^G_t = \bar{R}^G_t - 1$ each period. In addition, the principal is paid to the holder with probability $1-\theta_g$. This implies that the average duration of the government bond is $(1-\theta_g)^{-1}$. The law of motion of government bonds is therefore:

$$B_t = \theta_g B_{t-1} + B^N_t. \tag{8}$$

Without loss of generality, and to keep the same notation as with private sector bonds, let's denote $B_t^N = (1-\theta_g)\bar{B}_t$. This will allow us to re-write the law of motion (8) in a similar way to equation (6). Finally, we can express total revenues rev_t^G earned on the portfolio of government bonds in a similar way to equation (7) and define the average return on the government bond portfolio by $R_t^G \equiv \frac{rev_t^G}{B_t}$, which is a weighted average of past long-term government bond interest rates.

2.2.3 Banking Sector

The balance sheet of the representative bank is defined by its real assets holdings ($len_t + b_t$), where $b_t = B_t/P_t$, which are financed through the real net worth of the bank, $n_t = N_t/P_t$, and real deposits, $d_t = D_t/P_t$, collected from households:

$$len_t + b_t = n_t + d_t.$$

Net worth (or bank capital) is accumulated over time as the difference between earnings on assets and interest payments to households:

$$n_t = (1-\tau_B)[R_{t-1}^L \frac{P_{t-1}}{P_t} len_{t-1} + R_{t-1}^G \frac{P_{t-1}}{P_t} b_{t-1} - R_{t-1} \frac{P_{t-1}}{P_t} d_{t-1}] \exp(\varepsilon_t^{nw}), \tag{9}$$

where R_t is the short-term nominal deposit rate. As explained above, we interpret τ_B as an insurance premium, which helps keep bank capital bounded. ε_t^{nw} is an iid shock to banks' net worth. Bankers maximize their expected terminal wealth, which after they retire is transferred as dividends to the households they belong to. Every period bankers can divert a certain fraction of assets and also transfer them to the household they belong to. When bankers divert funds, the bank will be closed and the remaining assets serve as bankruptcy assets. Due to such an agency problem between banks and depositors, the latter demands that bankers have "skin in the game" requiring from them to hold equity N_t. Thus, the following incentive constraint must be satisfied:

$$\mathcal{V}_t \geq \lambda_t \left(len_t + \Delta_t b_t \right), \tag{10}$$

where $\mathcal{V}_t$ is the expected terminal wealth of the bank (defined by the present value of the expected future net worth), λ_t is the time-varying fraction of loans that can be diverted, and $\lambda_t \Delta_t$ is the time-varying fraction of government bonds which bankers can embezzle. If $\Delta_t < 1$, banks will find it easier to divert corporate bonds than government bonds. As a result, the excess return on government bonds is only a fraction Δ_t of the excess return on private securities. The shares λ_t and Δ_t follow AR(1) processes in logs. Following Gertler and Karadi (2013), we describe the optimization in the online appendix. However, we want to highlight a few optimality conditions here. The optimal portfolio choice for bankers leads to:

$$(1-\tau_B)E_t\beta\frac{\Xi_{t+1}}{\Xi_t}\Omega_{t+1}\left(R_t^L-R_t\right)\frac{P_t}{P_{t+1}}=\lambda_t\frac{\Theta_t}{1+\Theta_t},$$

where Θ_t is the Lagrange multiplier associated with the participation constraint (10), and Ω_t is the shadow value of a unit of net worth to the banker. With a binding participation constraint, the Lagrange multiplier is positive and the participation constraint implies that $\left(R_t^L-R_t\right)>0$. The size of the spread depends on the tightness of the constraint and the exogenous shock λ_t. Also, the optimizing conditions imply the following imperfect substitutability condition between corporate bonds and government bonds $\left(R_t^G-R_t\right)=\Delta_t\left(R_t^L-R_t\right)$. Investor demand return equalization up to a factor Δ_t, which in our model is a shock rather than a constant as in Gertler and Karadi (2013).

2.3 Households and Wage Setting

As in Gertler and Karadi (2011), we introduce a continuum of households in the economy and differentiate between two types of household members: workers and bankers. Workers supply labor L_t and bring wage income W_tL_t to the household while bankers manage financial intermediaries and bring profits to the household. All household members perfectly pool their consumption risk, with C_t describing non-durable consumption spending. Households can only save in deposits D_t, which pay the nominal deposit rate R_t. We introduce (internal) habit formation in consumption and assume a utility function, which is separable in consumption and hours worked, and which is hit by intertemporal and intratemporal disturbances. Consumption is determined via a standard Euler equation that depends on real interest rates and the intertemporal preference shock.

Following Erceg *et al.* (2000), each household is a monopolistic supplier of specialized labor. When bargaining wages, this allows households to charge a mark-up over their marginal cost of supplying labor. The market power of households and the associated mark-up is assumed to be time-varying. For the reasons explained above, we deviate from Justiniano *et al.* (2013) and do not implement the wage rigidity in the spirit of Calvo (1983), but follow the Rotemberg (1982) quadratic adjustment cost instead. Wages are partially indexed to past inflation and TFP growth. Beyond this, households can further adjust wages but they have to pay quadratic adjustment costs to do so.

2.4 The Government

Conventional monetary policy is conducted by the central bank with an interest rate rule that targets CPI inflation, π_t, and real output growth, Y_t/Y_{t-1}. Let π be the inflation target of the central bank, R be the steady-state level of the nominal interest rate, $\exp(\Lambda)$ be the growth rate of GDP along the balanced growth path, and $\varepsilon_{m,t}$ be an i.i.d. monetary policy shock. The deposit rate is given by:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\gamma_R} \left(\frac{\pi_t}{\pi}\right)^{\gamma_\Pi(1-\gamma_R)} \left[\frac{Y_t/Y_{t-1}}{\exp(\Lambda)}\right]^{\gamma_y(1-\gamma_R)} \exp(\varepsilon_{m,t}).$$

The ratio of government spending to GDP ($g_t = G_t/Y_t$) follows an AR(2) process:

$$\log(g_t) = (1-\rho_{g_1}-\rho_{g_2})\log(g) + \rho_{g_1}\log(g_{t-1}) + \rho_{g_2}\log(g_{t-2}) + \varepsilon_{g,t}$$

where $\varepsilon_{g,t} \sim \mathcal{N}(0, \sigma_g)$ is a shock to government spending. The choice of an AR(2) process is empirical, and we discuss the calibration in Section 3.1. We also assume that the supply of government bonds as percent of GDP is exogenous with an AR(1) process:

$$\frac{b_t}{Y_t} = (1-\rho_b)\frac{b}{Y} + \rho_b \frac{b_{t-1}}{Y_{t-1}} + \varepsilon_{b,t}$$

where $\varepsilon_{b,t} \sim \mathcal{N}(0, \sigma_b)$ is a shock to the supply of government bonds. Implicitly, we assume that given a path for exogenous government spending and the debt/GDP ratio, the government will adjust lump-sum transfers such that the government budget constraint holds.

3 Model Estimation

As is standard in the literature, we evaluate welfare by taking a second order approximation of the model's equilibrium conditions and to the household's utility function. Therefore, we need to obtain parameter estimates that ensure that the second order approximation of the model fits the data well. Because we are departing from the assumption of linearization, the standard way of proceeding to estimate DSGE models does not apply, which involves using the solution of the model in state-space form and the Kalman filter to evaluate the likelihood function of the linearized model, as explained in An and Schorfheide (2007).[9] To ensure a good fit, we estimate the model using a Generalized Method of Moments (GMM) procedure as in Christiano and Eichenbaum (1992), Ruge-Murcia (2007), and Andreasen *et al.* (2016). We use seven macroeconomic series that were used by Justiniano *et al.* (2013) on US data: real GDP, real consumption, real investment, hours worked, nominal wage growth, GDP deflator inflation, and the Federal Funds target between 1964:2 and 2009:4. In addition, we include two spreads: the spread between BAA corporate yields and the Federal Funds rate as well as the spread between 10 year Treasury and the Federal Funds rate.

3.1 Parameter Estimates

We estimate the model by taking a second order approximation to the equilibrium conditions and applying a GMM methodology. Let $data_t$ denote the nine macroeconomic and financial time series we described above. We estimate the model by matching the first moments, the contemporaneous second moments, and the persistence in the data. Hence, denote

$$M_t \equiv \begin{bmatrix} data_t \\ vech(data_t data_t') \\ diag(data_t data_{t-1}') \end{bmatrix}$$

where the $vech()$ operator selects the lower triangular elements of a matrix and orders them in a vector, and the $diag()$ operator selects the diagonal elements of a matrix. The size of the M_t vector is 63×1. Letting Θ denote the vector of structural parameters that we wish to estimate, the GMM estimator is given by:

$$\hat{\Theta}_{GMM} = \arg\min \left(\frac{1}{T} \sum_{t=1}^{T} M_t - \mathbb{E}[\mathbf{M}(\Theta)] \right)' \mathbf{W} \left(\frac{1}{T} \sum_{t=1}^{T} M_t - \mathbb{E}[\mathbf{M}(\Theta)] \right)$$

[9] Likelihood based methods for higher order approximations to the equilibrium conditions include the use of non-linear filters such as the particle filter, but they are computationally intensive (see, for instance, Fernández-Villaverde and Rubio-Ramírez, 2007).

Table 1: Calibrated Parameters

ε_L	Elasticity of Substitution between Labor	5
ε_Y	Elasticity of Substitution between Goods	10
α	Capital Share of Output	0.33
δ	Depreciation Rate	0.025
$1/(1-\theta_k)$	Average Duration between Capital Stock Changes	12
$1/(1-\theta_g)$	Average Duration of Government Debt	40
g	Government Spending/Output Ratio	0.2
ρ_{g_1}	AR(1) Coefficient for G_t/Y_t Ratio	1.288
ρ_{g_2}	AR(2) Coefficient for G_t/Y_t Ratio	-0.299
σ_g	Standard Deviation Innovation G_t/Y_t Ratio	1.07%
b/Y	Debt to GDP Ratio	0.45
L	Steady-State Hours	1

where $\mathbb{E}([\mathbf{M}(\Theta)]$ denotes the model-implied moments that are counterparts to M_t when taking a second order approximation to the model conditions. $\mathbf{W}$ is a weighting matrix, which is positive definite. We use a conventional two-step approach. First, we use an identity matrix for $\mathbf{W}$ to obtain an initial estimate of the parameters, that we denote by Θ_0. Then, we use the inverse of the variance-covariance matrix of $\left(\frac{1}{T}\sum_{t=1}^{T} M_t - \mathbb{E}[\mathbf{M}(\Theta_0)]\right)$ as the weighting matrix, which is obtained with a Newey-West estimator with 10 lags.

Some parameters are calibrated before estimation (see Table 1) and are excluded from Θ. We calibrate these parameters because they are either poorly identified from the data, or because we use other external sources to calibrate them. The elasticities of substitution are calibrated such that steady-state mark-ups are 10% in the product and 25% in the labor market. The capital share of output and the depreciation rate are calibrated according to standard values in the literature. We calibrate the average duration of capital stock upgrades to 12 quarters, following the calibration of Sveen and Weinke (2007). We calibrate the average duration of government debt to 40 quarters (10 years) because this is our counterpart in the data (the 10 year bond). We obtain the parameters for the government spending shock by fitting an AR(2) process on the (log) government spending/GDP ratio in US data. The parameters g, ρ_{g_1},ρ_{g_2}, and σ_g come from that regression. Finally, we calibrate the government debt/GDP ratio as in Gertler and Karadi (2013), and we normalize steady-state hours to 1 (this is the same normalization as in Justiniano *et al.*, 2013).

Table 2: Estimated Parameters

	Parameters	GMM	Standard Dev.
h	Habit Formation	0.742	0.026
φ	Inverse Frisch Elasticity	0.847	0.077
$1/\beta - 1$	Discount (in %)	0.241	0.025
$\log(R^L)$-$\log(R)$	Corporate Spread (in %, quarterly)	0.388	0.011
$\log(R^B)$-$\log(R)$	Government Spread (in %, quarterly)	0.144	0.006
Λ	TFP Growth (in %, quarterly)	0.425	0.015
η_i	Investment Adjustment Costs	8.43	0.85
θ_w	Wage Adjustment Cost	175.33	17.78
χ_w	Wage Indexation	0.707	0.041
θ_p	Price Adjustment Cost	62.76	4.61
χ_p	Price Indexation	0.421	0.044
ω	Capital Goods Producer Fees	0.0248	0.0009
θ_b	Probability of Banker Survival	0.919	0.044
ϕ	Steady-state Leverage Ratio	15.96	1.35
γ_Π	Taylor Rule Coefficient: Inflation	1.255	0.071
γ_R	Interest Rate Smoothing	0.606	0.036
γ_y	Taylor Rule Coefficient: Output Growth	0.12	0.007
π	Inflation Target	0.972	0.097

Table 2 presents the estimated parameters using GMM. We present the asymptotic standard errors which are computed using the asymptotic expression for the variance-covariance matrix of the parameters under GMM estimation and an optimal weighting matrix:

$$\sqrt{T}(\hat{\Theta} - \Theta_0) \xrightarrow{d} N\left(0, \left(\mathbf{D_o'}\left(\mathbf{S_o}\right)^{-\mathbf{1}}\mathbf{D_o}\right)^{-1}\right)$$

where we evaluate these matrices at the estimated parameter values:

$$\mathbf{D_o} = \frac{\partial h(M_t, \Theta)}{\partial \Theta'} \mid_{\Theta = \hat{\Theta}_{GMM}},$$
$$h(M_t, \Theta) = \frac{1}{T}\sum_{t=1}^{T} M_t - \mathbb{E}[\mathbf{M}(\Theta)],$$

and $\mathbf{W} = (\mathbf{S_o})^{-\mathbf{1}}$ is the optimal weighting matrix.

Most parameter estimates are in line with previous papers and contributions. We do not impose any type of prior information on the estimation, but for most parameters we impose non-negativity constraints, and for some parameters we also impose an upper bound (for instance, fractions such as indexation coefficients, and AR(1) coefficents have to be between [0,1]). These restrictions do not appear to be binding, since in all cases except the estimated AR(1) coefficient for the financial shock that affects the tightness of the participation constraint, the estimation procedure finds an interior solution.

Table 3: Estimated Parameters

	Parameters	GMM	Standard Dev
ρ_b	AR(1) Government Debt	0.833	0.098
ρ_u	AR(1) Preference	0.967	0.015
ρ_I	AR(1) Investment	0.558	0.067
ρ_λ	AR(1) Lambda	0.999	0.0003
ρ_ψ	AR(1) Labor supply	0.623	0.053
ρ_Z	AR(1) Transitory TFP	0.947	0.033
ρ_A	AR(1) Permanent TFP	0.289	0.029
ρ_{ε_Y}	AR(1) Goods Elasticity	0.871	0.186
ρ_Δ	AR(1) Delta	0.124	0.019
σ_b	SD Government Debt	0.673	0.088
σ_u	SD Preference	0.019	0.005
σ_I	SD Investment	0.075	0.016
σ_λ	SD Lambda	0.046	0.009
σ_ψ	SD Labor Supply	0.144	0.023
σ_Z	SD Transitory TFP	0.007	0.0005
σ_A	SD Permanent TFP	0.005	0.0007
σ_{ε_Y}	SD Price Markup	0.034	0.009
σ_Δ	SD Delta	0.138	0.039
σ_{ε_L}	SD Wage Markup	0.244	0.046
σ_m	SD Monetary	0.0033	0.0003
σ_{nw}	SD Net Worth	0.184	0.021

Despite the differences in the estimation procedure, the parameter estimates are similar to other papers in the literature that use Bayesian methods and a linearized version of the model. The habit formation parameter is estimated at 0.74, while in the inverse Frisch elasticity of labor supply is 0.84. The implied estimated β is 0.9975. The estimated steady-state values for the corporate and government sector spreads imply that the mean of the financial shock that affects the tightness of the participation constraint for government bonds (Δ_t) is 0.78. The growth rate of TFP is about 1.6 percent annual rate, as in Christiano *et al.* (2014). The parameters related to the behavior of investment adjustment costs, price and wage rigidities, and behavior of the banking sector are also within the range of other model-based evidence or empirical studies. Interestingly, we find that the steady-state leverage ratio is close to 16, which is much higher than the calibrated value in Gertler and Karadi (2011), but is also closer to the data for financial institutions before the crisis. The estimates for the Taylor rule are on the lower side, with smaller reactions to inflation deviations (1.25), output growth deviations (0.12) and interest rate smoothing coefficients (0.6) than other studies such as Justiniano *et al.* (2013) and Smets and Wouters (2007).

Table 3 presents the estimated parameters for all the shock processes. It is difficult to compare these estimates with other papers, because changes in modeling assumptions lead to changes in the parameter estimates of the shocks. It is worth noting that only one shock is extremely persistent, the λ_t shock included in the participation constraint (10). Also, as in Justiniano *et al.* (2013), the growth rate of the permanent TFP shock displays low persistence.

4 Model Fit

Since the number of moment conditions is greater than the number of estimated parameters, the model is overidentified. In this case, a model specification J-test is given by:

$$J = Th(M_t, \Theta)'(S_o)^{-1}h(M_t, \Theta) \xrightarrow{d} \chi^2_{n_m - n_\Theta}.$$

where n_m is the number of moments and n_Θ is the number of parameters. The idea is to check whether $h(M_t, \hat{\Theta}_{GMM})$ is sufficiently close to zero to suggest that the model fits the data well. We find that the null hypothesis that the model is valid cannot be rejected with a p-value of 0.71.[10]

In order to better understand how well the model fits the data, we present the means and standard deviations of each variable, all contemporaneous correlations, and the first autocorrelation of each variable in the data and in the model (Tables 4 and 5).[11] The fit to the mean of the variables is very good. The only exception is the growth rate of investment, which is higher in the model than in the data. At this point, it is worth emphasizing that there are important risk corrections in the model once second order effects are taken into account. For instance, in the non-stochastic steady state the spreads over the Federal Funds rate were estimated to be 0.38 percent (on a quarterly basis) for the corporate sector and 0.14 percent for the government. However, when second order effects are taken into account, the spreads become 0.61 and 0.23 respectively, and closer to the

[10] More specifically, the values for the *J-test* are as follows: T=183, the value of the objective function at the optimum is 0.108, $n_m = 63$, and $n_m = 39$.

[11] Recall that the estimation procedure matches $E(M_t)$, $E(M_tM_t')$ and $diag[E(M_tM_{t-1}')]$. We present means, standard deviations and correlations as it is typically done in assessing the goodness of fit of a model.

data (0.71 and 0.22). The level of the spread affects the level of investment and the capital stock in the model, as well as consumption. Therefore, if we had estimated the model up to first order and then performed welfare analysis up to second order, our baseline welfare evaluation would not be aligned with the data. There are also risk corrections for the mean of inflation (0.97 in the non-stochastic steady state and 0.91 up to second order) and hours (0 in the steady state, 0.16 percent in the second order approximation), but these are minor.

Table 4: Model Fit

Variable	Data			Model		
	Mean	Std Dev.	Autocorr	Mean	Std. Dev.	Autocorr
GDP Growth	0.40	0.86	0.32	0.42	0.85	0.38
Consumption Growth	0.50	0.52	0.47	0.42	0.50	0.70
Investment Growth	0.26	3.32	0.30	0.42	3.33	0.26
Wage Growth	1.35	0.73	0.46	1.33	0.71	0.68
Inflation	0.95	0.60	0.87	0.91	0.62	0.89
Federal Funds Rate	1.54	0.84	0.95	1.56	0.76	0.87
Hours	0.00	3.74	0.98	0.16	3.75	0.95
Spread BAA-FFR	0.71	0.53	0.90	0.61	0.69	0.85
Spread 10Y Bond-FFR	0.22	0.43	0.88	0.23	0.26	0.84

Table 5: Model Fit

Correlation	Data	Model	Correlation	Data	Model
(GDP,C)	0.57	0.62	(INV,H)	0.03	0.02
(GDP, INV)	0.88	0.85	(INV,BAA-FFR)	0.05	0.01
(GDP, W)	-0.13	-0.13	(INV,10Y-FFR)	0.21	0.01
(GDP, INFL)	-0.24	-0.38	(W, INFL)	0.66	0.65
(GDP, FFR)	-0.14	-0.23	(W,FFR)	0.46	0.52
(GDP, H)	0.12	0.10	(W,H)	-0.18	-0.24
(GDP, BAA-FFR)	0.05	0.06	(W, BAA-FFR)	-0.42	-0.03
(GDP, 10Y-FFR)	0.22	0.06	(W,10Y-FFR)	-0.43	-0.03
(C,INV)	0.34	0.28	(INFL,FFR)	0.65	0.76
(C,W)	-0.11	-0.06	(INFL, H)	-0.38	-0.31
(C,INFL)	-0.33	-0.45	(INFL,BAA-FFR)	-0.49	-0.07
(C,FFR)	-0.10	-0.33	(INFL,10YFFR)	-0.52	-0.07
(C,H)	0.20	0.13	(FFR, H)	-0.38	-0.42
(C, BAA-FFR)	0.00	0.11	(FFR,BAA-FFR)	-0.49	-0.24
(C, 10Y-FFR)	0.17	0.11	(FFR,10YFFR)	-0.52	-0.24
(INV,W)	-0.05	-0.13	(H,BAA-FFR)	-0.33	-0.26
(INV, INFL)	-0.11	-0.24	(H,10Y-FFR)	-0.24	-0.26
(INV, FFR)	-0.10	-0.11	(BAA-FFR, 10Y-FFR)	0.94	0.997

When it comes to matching second moments, the estimated model explains the standard deviations and autocorrelations fairly well. The model has trouble matching the volatility of the spreads, because both the mean and the standard deviation of the government sector spreads are a fraction Δ_t of the mean and standard deviation of the corporate spreads. The estimated model is not able to overcome this tight relationship between the two variables, even though Δ_t is stochastic, because it is not volatile enough. The model fit to contemporaneous correlations is also very good. In fact, in all thirty-six cases, the estimation procedure gets the bilateral contemporaneous correlation sign right. The model also explains the persistence of variables well. It only fails in overpredicting the persistence of real consumption and nominal wage growth.

Table 6: Shock Decomposition

Variable	TFP	Inv	Pref	Fin	Mark-ups	Govt	Mon
GDP Growth	40.7	9.7	19.0	15.8	2.6	3.8	8.6
Consumption Growth	47.9	1.6	39.4	0.9	1.6	4.5	4.1
Investment Growth	21.2	14.5	25.2	28.4	2.0	0.6	8.0
Wage Growth	28.7	6.8	56.9	3.2	2.2	1.1	1.2
Inflation	39.3	3.9	46.1	3.3	4.2	1.9	1.3
Federal Funds Rate	24.1	4.1	41.4	3.5	2.5	1.9	22.6
Hours	9.1	8.3	50.3	18.2	2.9	9.3	2.0
Spread BAA-FFR	2.5	0.2	1.5	85.5	0.4	0.1	9.9
Spread 10Y Bond-FFR	2.5	0.2	1.4	85.6	0.4	0.1	9.8

Next, we report the variance decomposition through the lens of the model. In order to facilitate the reading of Table 6 we aggregate the shocks into preference (intertemporal and intratemporal), TFP (temporary and permanent), investment-specific, financial (λ_t, Δ_t, net worth, and debt supply), market power (prices and wages), government spending and monetary shocks. Both TFP shocks explain around 40 percent of the fluctuations in output growth, consumption growth, and inflation. Financial shocks are also important, because they explain about 15 percent of GDP fluctuations. Their effect is particularly strong in investment, where they explain about 28 percent of fluctuations, and also in hours, explaining about 18 percent. Furthermore, financial shocks explain more than 80 percent of the fluctuations in both spreads (government bonds and corporate bonds). Preference shocks also explain an important share (between one-third and one-half of fluctuations) of most macroeconomic variables, and up to 50 percent of the volatility of hours. Mark-up, monetary policy and government spending shocks explain small fractions of economic fluctuations.Up to this section, we have estimated the model with financial frictions but with monetary policy being conducted with a Taylor-type rule. In the following section, we examine the benefits of using UMP in normal times, under the estimated Taylor rule and under other conventional monetary policy rules.

5 Implementing UMP in the Model

UMP in our model is implemented via asset purchase programs and the central bank purchases either private or government sector debt.

5.1 Direct Lending to Firms

Similar to Gertler and Karadi (2011) the central bank provides financing to firms by extending credit directly (or, what is equivalent in the context of this model, by purchasing corporate debt). Gertler and Karadi (2011) assume that the public credit policy is to provide a fraction Ψ_t of the stock of credit for firms to borrow. Here, we assume that the central bank UMP rule is in terms of the level of credit (which is more consistent with central banks statements which describe actual amounts rather than fractions). Aggregate lending is given by:

$$len_t = (1-\theta_k)\frac{P_t^K}{P_t}\bar{K}_t + \theta_k\frac{P_{t-1}}{P_t}len_{t-1}$$

where $len_t = len_t^p + len_t^{cb}$, and where len_t^p stands for commercial bank credit to the private sector and len_t^{cb} is central bank credit to the private sector. As we discuss in the appendix, when the central bank lends to the private sector, it reduces the banking sector leverage, thus putting downward pressure on corporate sector spreads.

5.2 Purchases of Government Bonds

In this case the central bank buys government bonds and tries to affect the corporate spread by inducing a portfolio reallocation away from government bonds by banks. The law of motion of government bonds is given by:

$$B_t = (1-\theta_g)\bar{B}_t + \theta_g\frac{P_{t-1}}{P_t}B_{t-1}$$

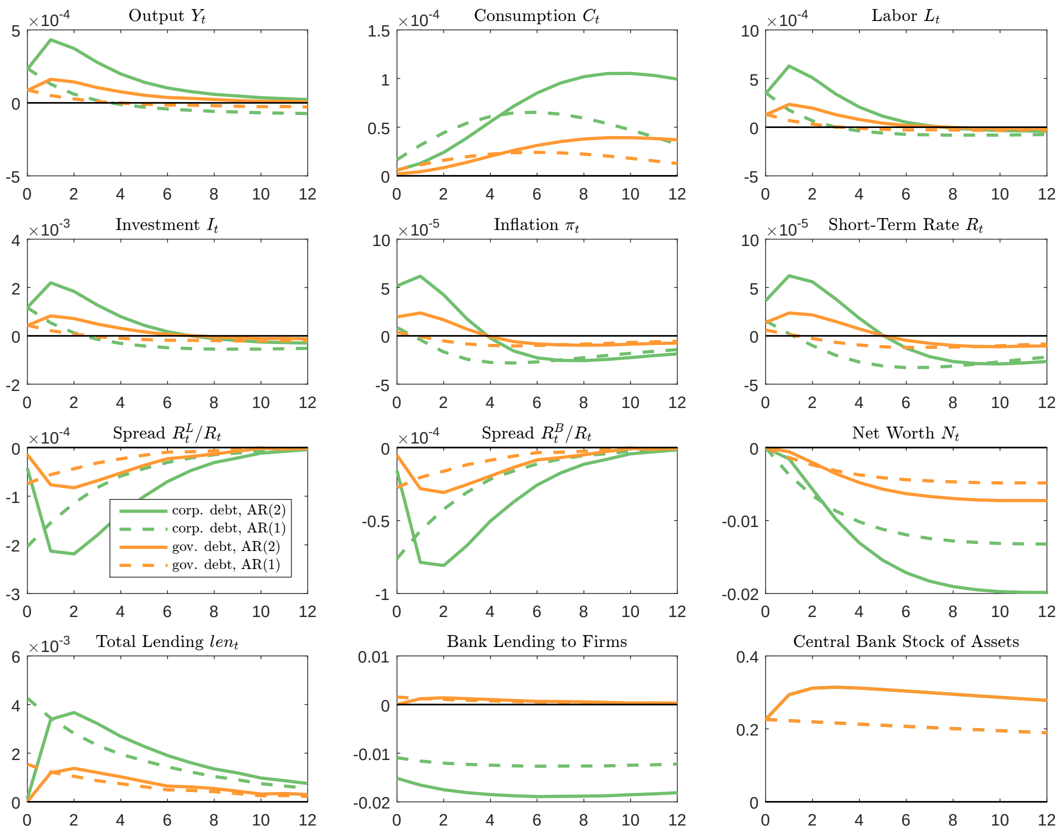
where $B_t = B_t^p + B_t^{cb}$, and where B_t^p stands for commercial bank credit to the government, and B_t^{cb} is central bank purchases of government bonds. When the central bank buys government bonds, it reduces the amount of government debt being financed by the private financial sector. This reduced bond supply leads to higher bond prices, lower yields and spreads of goverment bonds. This will reduce corporate spreads too, through the imperfect asset subtitutability condition, and increase investment, employment and GDP.

5.3 The Effects of UMP

To get a sense of what UMP does in the model, in Figure 1 we plot the impulse responses to a UMP shock, when we take central bank purchases as an exogenous process. Figure 1 shows the case when the stock of assets held by the central bank follows an AR(1) or AR(2) process and UMP is conducted by either lending directly to firms or purchasing government bonds. Two results stand out. First, the impact of UMP policies is stronger when the central bank lends directly to firms than when it purchases government bonds, because it directly affects the private sector spreads, which have a stronger macroeconomic impact. This result echoes the findings of Gertler and Karadi (2013), and means that if UMP is to be implemented via purchases of government bonds, it needs to be deployed at a larger scale. Second, comparing the AR(1) with the AR(2) process shows that the latter has strong expansionary effects in our model, showing that announcement effects and a commitment to not to unwind UMP policies in the near future are key to a successful implementation.

Under a persistent AR(1) shock, the stock of assets increases on impact and the central bank starts unwinding UMP already in $t = 1$. The effect of these policies is expansionary on impact because of reduced spreads and increased investment, labor demand and GDP. However, this effect is short-lived, and turns negative three quarters after the initial shock. The key to understand this result is that by engaging in UMP policies, the central bank worsens the balance sheet position of financial intermediaries. Hence, when the initial UMP impulse is scaled down, banks' reduced net worth does not allow to provide the necessary credit to sustain a higher level of activity, and an investment contraction follows. Because of the reduction in spreads, and the fact that wages are sticky, inflation barely increases on impact and starts declining thereafter. However, this quantitative effect is small.

Figure 1: Impulse Response to an Exogenous AR(1) or AR(2) UMP Shock



NOTE: The stock of assets held by the central bank follows either an AR(1) or AR(2) process. For the AR(1) process we set the coefficient of the first lag equal to 0.985 while for the AR(2) process we set the coefficients of the first lag equal to 1.3 and of the second lag equal to -0.31. Thus, the largest root of both processes is 0.985. The impulse responses are computed after taking a second order approximation to the equilibrium conditions of the model.

Using an AR(2) process fits the implementation of UMP policies by major central banks better, when an announcement of future purchases of securities was generally made, and implemented over the following quarters (see Chen *et al.*, 2012 and Gertler and Karadi, 2013). In this case, the expansionary effects of UMP are long-lasting leading also to an increase in inflation. On the one hand, the decline in net worth is stronger due to the pronounced fall in spreads so that the incentive constraint (10) tightens more compared with the AR(1) process. On the other hand, the persistence of the UMP shock lowers spreads for a longer period of time, thereby improving refinancing conditions. Given the forward looking behavior of intermediate goods producers, the increase in investment spending is higher, which leads to a persistent, hump-shaped increase in output and employment. This section has shown the effects of UMP policies when they are considered to be exogenous. From a welfare point of view, simply including additional exogenous shocks to the model would simply reduce welfare. In practice, during the crisis, UMP was deployed because it was reacting to adverse financial conditions. In the following section, we study the optimality of UMP rules that explicitly react to credit spreads.

6 Welfare Analysis

In this section, we quantify the benefits of deploying UMP as a standard monetary policy measure with a rule. The main benefit of including an additional policy instrument is to provide an additional tool for macroeconomic stabilization. Gertler and Karadi (2011) discuss the main cost of implementing UMP via lending to the private sector, which is that the central bank is more inefficient than the private financial sector in intermediating credit. Otherwise, given the structure of the model, it would be optimal for the central bank to replace commercial banks because it is not subject to an agency problem and is not leverage constrained. Since it is difficult to measure in the data how inefficient the central bank is compared to the private sector in intermediating credit, our results provide an estimate of how large those costs should be for UMP policies not to be worth pursuing. In addition, when UMP policies are implemented through purchases of government bonds, it is not clear that the central bank incurs any additional inefficiency cost of purchasing these bonds compared to having the banking sector buy them. Therefore, our estimates also provide an upper bound of how large the costs of intermediating credit should be, for UMP policies implemented via purchases of government bonds be preferrable to direct lending to firms. Also, as emphasized by Del Negro and Sims (2015) and Hall and Reis (2015), there may be fiscal implications if the central bank incurs in losses due as a consequence of large scale asset purchases. In this section, we compare the effects of UMP under the estimated Taylor rule, and under more optimal conventional monetary policy rules.

6.1 Using The Estimated Taylor Rule

First, we assess the optimality of UMP in the estimated model, with the estimated policy rule. We use as a welfare criterion the utility function of the representative household:

$$\mathbb{W}_t = \xi_t^{\mathscr{U}} \left[\log\left(C_t - hC_{t-1}\right) - \psi_t \frac{L_t^{1+\varphi}}{1+\varphi} \right] + \beta E_t \mathbb{W}_{t+1}$$

We take a second order approximation to the equilibrium conditions and to the welfare function. All the parameters of the model are set at their calibrated or estimated values (as in Tables 1 to 3). Lending intermediated by the central bank is given by the following rule:

$$len_t^{cb} = \rho_\Psi len_{t-1}^{cb} + \gamma_\Psi (R_t^L/R_t - R^L/R),$$

with R^L/R being the non-stochastic steady state spread. We also experiment with a rule that reacts to the spread on *new* lending rates (i.e. to $\bar{R}_t^L/R_t - R^L/R$) rather than *average* rates. Central bank government bond purchases are given by the following rule:

$$B_t^{cb} = \rho_\Psi B_{t-1}^{cb} + \gamma_\Psi (R_t^L/R_t - R^L/R)$$

We also experiment with a rule that reacts to the spread on *new* lending rates rather than *average* rates, as well as rules that react to the spread between government bond rates and short-term rates (both average and new). For each UMP rule, we optimize welfare over the coefficients ρ_Ψ and γ_Ψ taking as given the equilibrium conditions of the model. We discuss in the following section why we do not include a second lag in the policy reaction function.

6.1.1 Optimal Coefficients

In Table 7, we report the optimal coefficients, the value of the welfare function up to second order, and the difference (in stead-state consumption equivalence terms) from the estimated model (with an estimated Taylor rule and no UMP in place). All policies deliver quantitatively very similar results in terms of welfare. The highest welfare is achieved when the central bank either buys corporate or government bonds to target the average spread on private sector securities. While the coefficient on the responses varies, all these policies entail very large responses to spreads, which in practice it implies that spreads are flattened out.[12] In addition, we can see that using corporate or government bonds to achieve the results does not make a difference. The choice of implementing UMP with corporate or government bonds would make a difference if the Δ_t shock was very volatile. But, in our estimation, which reflects the behavior of spreads in normal times, it is not. The only case where UMP policies are not desirable is when the central bank buys government bonds to affect the spread on new government debt. It is worth emphasizing again that if providing credit to the private sector entails some inefficiency cost, then a policy that implements purchases of government debt targeting the average lending spread would be the preferred policy. It is interesting to note that when UMP is endogenous, the degree of optimal persistence is high, but never close to a unit root behavior. Hence, we do not study the role of further lags in the UMP reaction function.

Table 7: Optimal UMP Policy

Policy	ρ_Ψ	γ_Ψ	$\mathbb{W}_t$	C.E. (in %)
Corp., $\bar{R}_t^L - R_t$	0.972	3142.9	-577.72	1.41
Corp., $R_t^L - R_t$	0.636	37992.7	-577.56	1.45
Gov., $\bar{R}_t^L - R_t$	0.786	56688.6	-577.8	1.4
Gov., $R_t^L - R_t$	0.767	65934.6	-577.56	1.45
Gov., $\bar{R}_t^B - R_t$	0	0	-583.6	0
Gov., $R_t^B - R_t$	0.953	37985.4	-577.66	1.43

Next, we zoom in and examine whether UMP policies are desirable when only a subset of shocks is included. For the purpose of this exercise, we group shocks as follows:

- **Supply shocks.** This group includes: (i) permanent TFP shocks, (ii) transitory TFP shocks, (iii) investment-specific technology shocks, (iv) labor supply shocks, and (v) price and (vi) wage mark-up shocks.
- **Demand shocks.** This group includes: (i) the intertemporal preference consumption shock, (ii) the government spending shock, and (iii) the monetary shock.
- **Financial shocks.** This group includes: (i) the bank capital (net worth) shock, (ii) the fraction of corporate securities that can be diverted by the banker, (iii) the fraction of

[12] In the deterministic steady-state, the value of len_t^{cb} or B_t^{cb} is always zero. However, the mean of the second order approximation does not have to be zero, as it may incorporate risk-correction effects. The optimization procedure includes a large penalty when the mean of the variables len_t^{cb} or B_t^{cb} (as percent of GDP) falls outside the range [0,50]. We think that this restriction makes sense to avoid the fact that the central bank short-sells securities or accumulates a very large stock of securities. This is why a policy of "strict spread targeting" is not optimal in Table 7.

government securities that can be diverted by the banker, and (iv) the government debt supply shock.

Table 8: Optimal UMP Policy, Conditional

Policy	ρ_Ψ	γ_Ψ	$\mathbb{W}_t$	C.E. (in %)
Demand shocks				
Corp., $\bar{R}_t^L - R_t$	0.99	26352.9	-575.96	.13
Corp., $R_t^L - R_t$	0.58	1000000	-576.16	0.07
Gov., $\bar{R}_t^L - R_t$	0.99	7174.87	-575.96	.13
Gov., $R_t^L - R_t$	0.58	1000000	-576.16	0.07
Gov., $\bar{R}_t^B - R_t$	0.05	14067.2	-575.05	0.35
Gov., $R_t^B - R_t$	0.84	1000000	-576.16	0.07
Supply Shocks				
Policy	ρ_Ψ	γ_Ψ	$\mathbb{W}_t$	C.E. (in %)
Corp., $\bar{R}_t^L - R_t$	0.05	0	-577.41	0
Corp., $R_t^L - R_t$	0.87	1000000	-577.21	0.05
Gov., $\bar{R}_t^L - R_t$	0	0	-577.41	0
Gov., $R_t^L - R_t$	0.87	1000000	-577.21	0.05
Gov., $\bar{R}_t^B - R_t$	0.11	1136.9	-577.12	0.07
Gov., $R_t^B - R_t$	0.99	1000000	-577.21	0.05
Financial Shocks				
Policy	ρ_Ψ	γ_Ψ	$\mathbb{W}_t$	C.E.
Corp., $\bar{R}_t^L - R_t$	0.911	9236.6	-575.76	1.33
Corp., $R_t^L - R_t$	0.806	20417.1	-575.76	1.33
Gov., $\bar{R}_t^L - R_t$	0.801	54346.5	-575.76	1.33
Gov., $R_t^L - R_t$	0.971	9292.1	-575.74	1.34
Gov., $\bar{R}_t^B - R_t$	0	64317.3	-576.23	1.22
Gov., $R_t^B - R_t$	0.955	36800.4	-575.81	1.32

We could compute the optimal response to each particular shock, but we think that this grouping makes sense because it separates "conventional business cycle" supply and demand shocks, from financial shocks. Using this grouping, UMP policies are most relevant when financial shocks hit the economy (Table 8). In fact, most of the welfare gains come from responding optimally to this group of shocks, with a gain of 1.34 percent of steady-state consumption. When only financial shocks are present, the optimal UMP policy is conducted by government bonds affecting the average spread on corporate loans, and interestingly, it is a highly inertial policy, with a value of 0.971 for the inertia coefficient ρ_Ψ. Under demand or supply shocks, UMP brings about very small welfare gains (0.35 and 0.07 of lifetime consumption). Interestingly, under these conventional business cycle shocks, the best policy is to use government bonds to target the spread on new government rates (a policy that is not deployed at all when we consider all shocks).

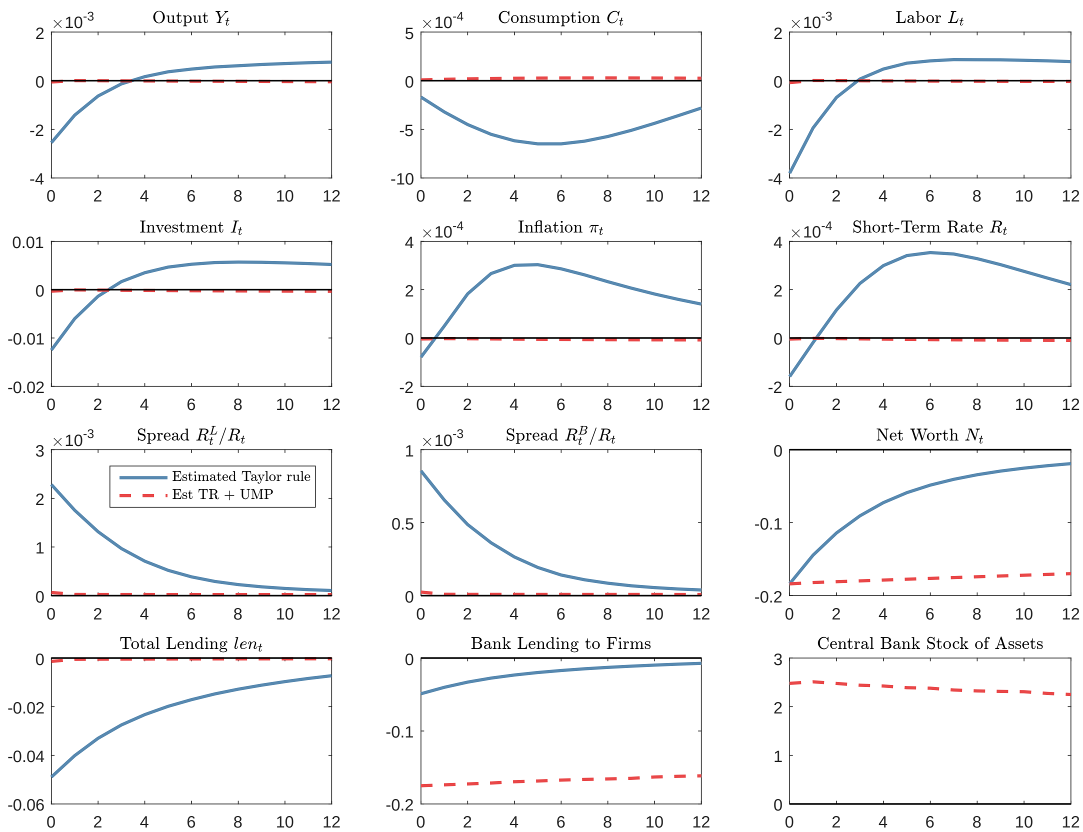
Hence, UMP is mostly useful when the economy is hit by financial shocks, but it is not when standard business cycle shocks drive fluctuations. This result echoes the finding of the literature of the usefulness of asset purchase programs in a financial crisis and when the economy hits the ZLB. Here, we have shown that the same applies away from the ZLB and smaller shocks. We have shown that when the sources of business cycles are not financial, then there is less need for making UMP part of the toolkit. In particular, it is worth emphasizing again that we have not quantified the possible costs of asset purchases. Gertler and Karadi (2011) assume that the central bank is less efficient than commercial banks intermediating credit, and thus there is an efficiency cost when the central bank directly lends to the private sector. The benefits of UMP should be weighted against these costs. We have not included these costs in the model because there is no evidence of how large they might be. And, in the case of QE policies, it is not clear that purchases of government bonds by the central bank are performed less efficiently than by private banks. Perhaps, the benefits of UMP should be compared to the fiscal or political economy costs that they entail, but again, it is difficult to quantify these costs.

6.1.2 Impulse Response Analysis

Here we discuss impulse responses to financial shocks as well as the effects of more standard supply and demand shocks. We examine the response under the estimated model, and under the model where UMP is conducted by purchasing corporate bonds, and reacting to the average lending-deposit spread (the optimal UMP in Table 7).

Figure 2 presents the impulse response to an adverse bank capital or net worth shock. In the estimated model, the shock reduces banks' net worth, and thus leads to to a decline in lending to the private sector, and an increase of spreads for both the corporate and the government sector. As a result, investment and employment decrease, and so does private consumption and real GDP. The response of inflation is muted because its two main components move in different directions: lending rates increase, but real wages (not shown) fall. After falling on impact, inflation therefore increases only by a small amount. Monetary policy basically follows the behavior of inflation through the Taylor rule. The use of UMP completely offsets this shock. In this case, because the shock is contractionary, the central bank lends to firms directly. As a result, aggregate lending does not fall and the spreads do not move. A similar result is obtained by Carlstrom *et al.* (2016) in a model with financial frictions and real and financial shocks like the one we presented here.

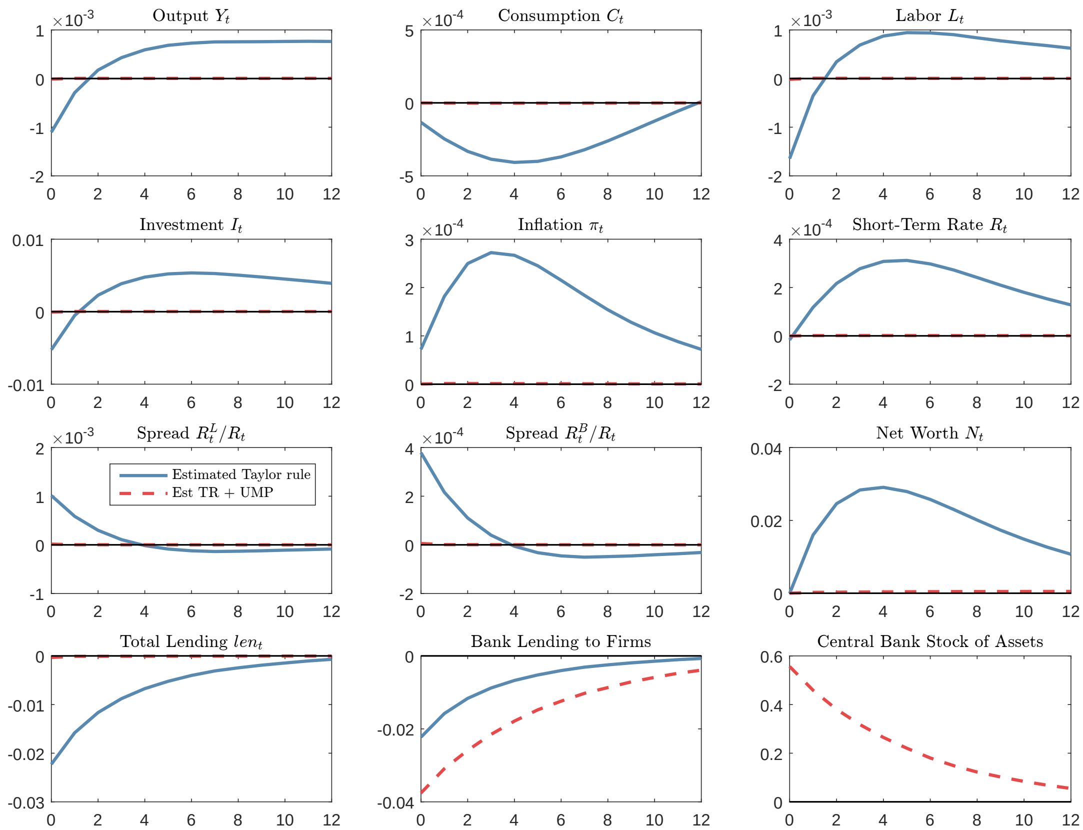
Figure 2: Impulse Response to a Net Worth Shock



NOTE: The impulse responses are computed after taking a second order approximation to the equilibrium conditions of the model.

Figure 3 presents the impulse response to an increase in government debt. This increase could be motivated by a reduction in tax revenue while keeping government spending constant. An increase in government debt that needs to be financed by the banking sector leads to an initial crowding out: spreads on both government and corporate debt increase, reducing lending, investment, labor demand, and hence GDP and consumption. Interestingly, the balance sheet position of banks improves because of the increased lending markings. However, the negative effects of this shock are short-lived, because this shock is not very persistent (the AR(1) coefficient is estimated to be 0.833). This means that spreads return quite rapidly to their steady-state values, and investment, labor demand and output rebound. UMP policies are extremely effective at insulating the

Figure 3: Impulse Response to a Government Debt Supply Shock



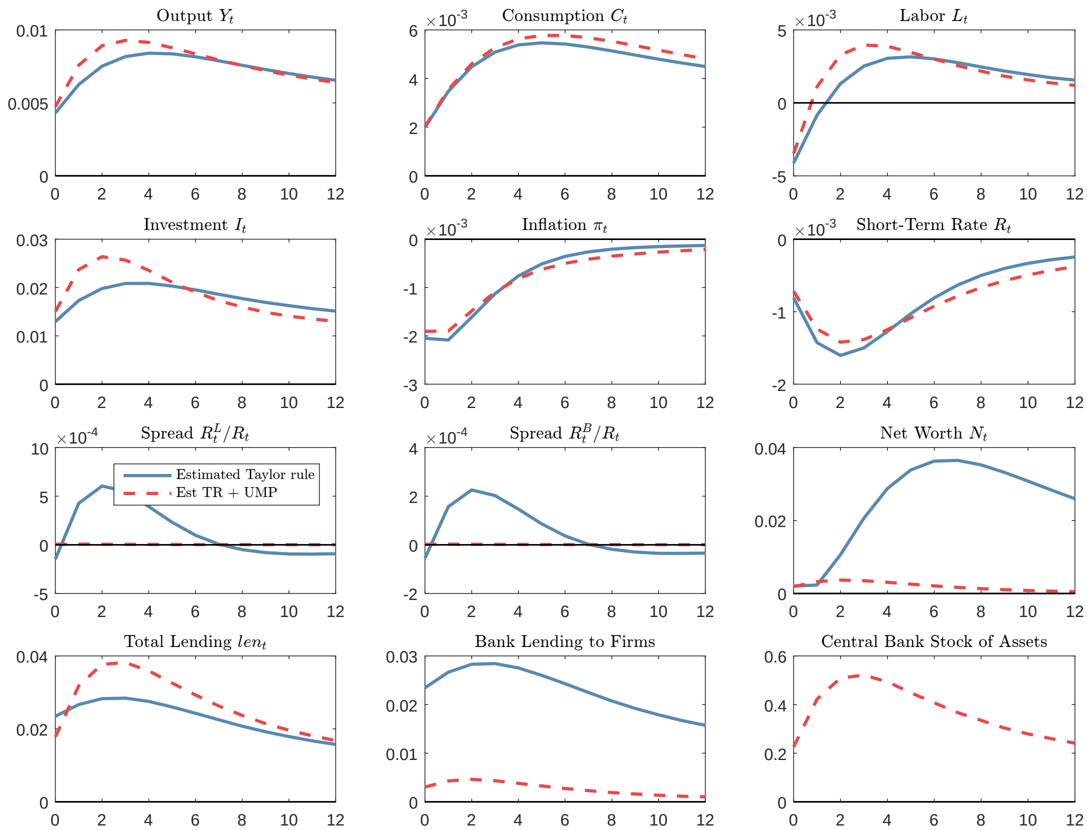
NOTE: The impulse responses are computed after taking a second order approximation to the equilibrium conditions of the model.

real economy from this shock.

Having established that UMP is useful when the economy is hit by financial shocks, we now study what happens when the economy is hit by more standard supply and demand shocks. For this purpose, we present the impulse responses to a temporary TFP shock, an investment-specific technology shock, a consumption preference shock, and a government spending shock.[13] The effects of a temporary TFP shock are fairly standard and similar to a model without financial frictions (see, for instance, Smets and Wouters, 2007). GDP, consumption and investment increase, while hours worked and inflation decline (Figure 4). The central bank cuts interest rates as a result. In the financial sector, lending increases immediately because of increased credit demand, but it

[13]The results are representative to what happens under any other supply or demand shock. To save space, we omit the analysis for all other supply and demand shocks in the model, but they are available upon request.

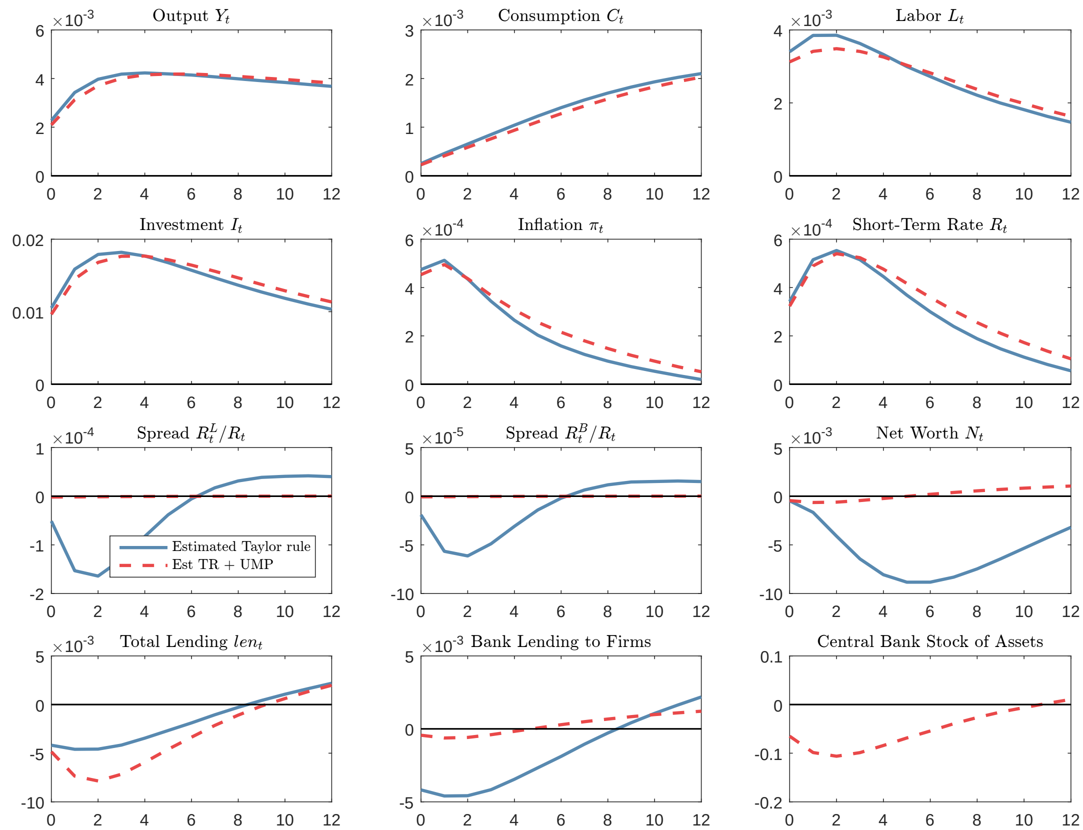
Figure 4: Impulse Response to a Temporary TFP Shock



NOTE: The impulse responses are computed after taking a second order approximation to the equilibrium conditions of the model.

takes a while for banks to accumulate more net worth: the leverage ratio (not shown) increases and so does the lending-deposit spread. In this sense, the financial friction dampens the initial effect of the shock because of the lack of resources to invest. Deploying UMP removes the financial friction and allows the economy to reap the benefits of higher productivity. In this case, the central bank is able to stabilize the spread completely, generating an even larger effect on investment and GDP. The effect on consumption and labor is much smaller, which explains why, in terms of welfare, the effect of UMP under supply shocks is small.

Figure 5: Impulse Response to an Investment-Specific Technology Shock

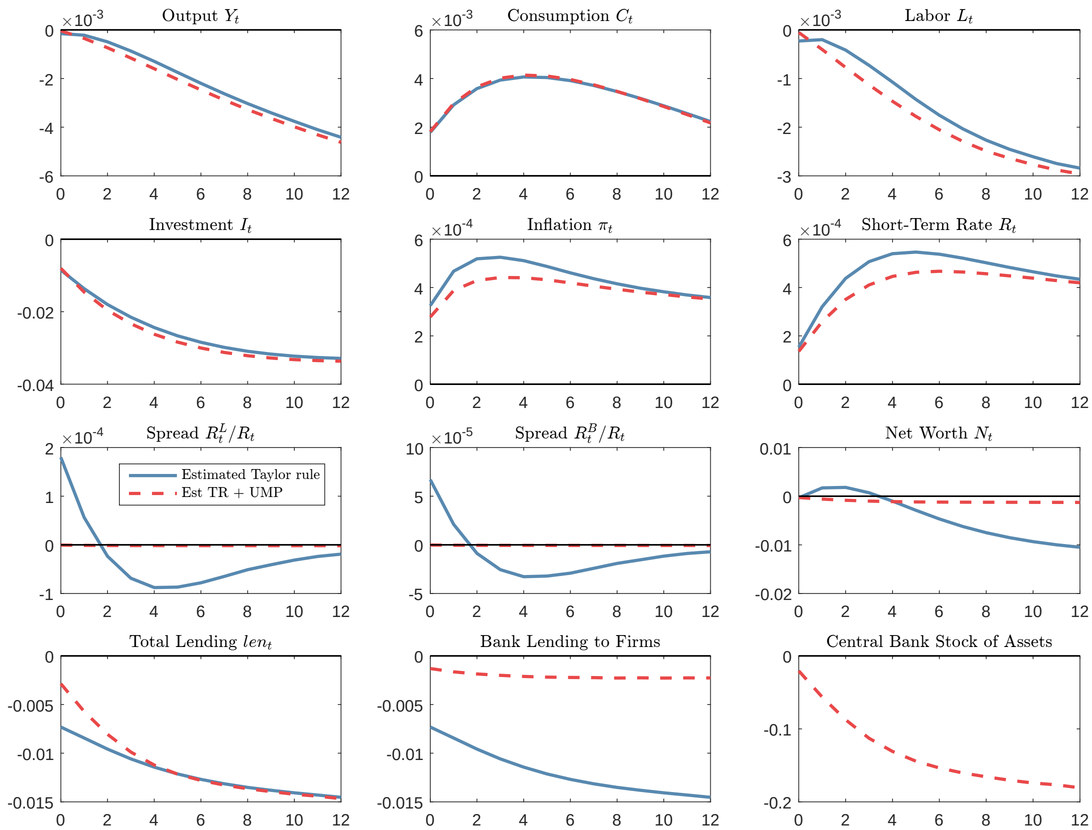


NOTE: The impulse responses are computed after taking a second order approximation to the equilibrium conditions of the model.

The effects of an investment-specific technology shock are also fairly standard, as in Justiniano *et al.* (2011) (Figure 5). Investment, GDP, consumption and labor increase. Unlike the case of the TFP shock, inflation also increases because the technology improvement is in the capital goods sector rather than the consumption goods sector, so the marginal cost of production in the latter actually increases. The inclusion of the financial sector and financial frictions has the following effect: in this case, total lending declines because the price of capital goods is cheaper: the amount that firms need to borrow, when expressed in nominal terms or in consumption goods, actually declines. This smaller demand for credit translates into lower spreads. Note, however, that the effect on spreads is quantitatively very small. As a result, when UMP policies aim at stabilizing spreads, the impulse responses with respect to the main macro variables do not really change.

The effects of a consumption preference shock are also fairly standard (Figure 6). They lead to

Figure 6: Impulse Response to a Consumption Preference Shock

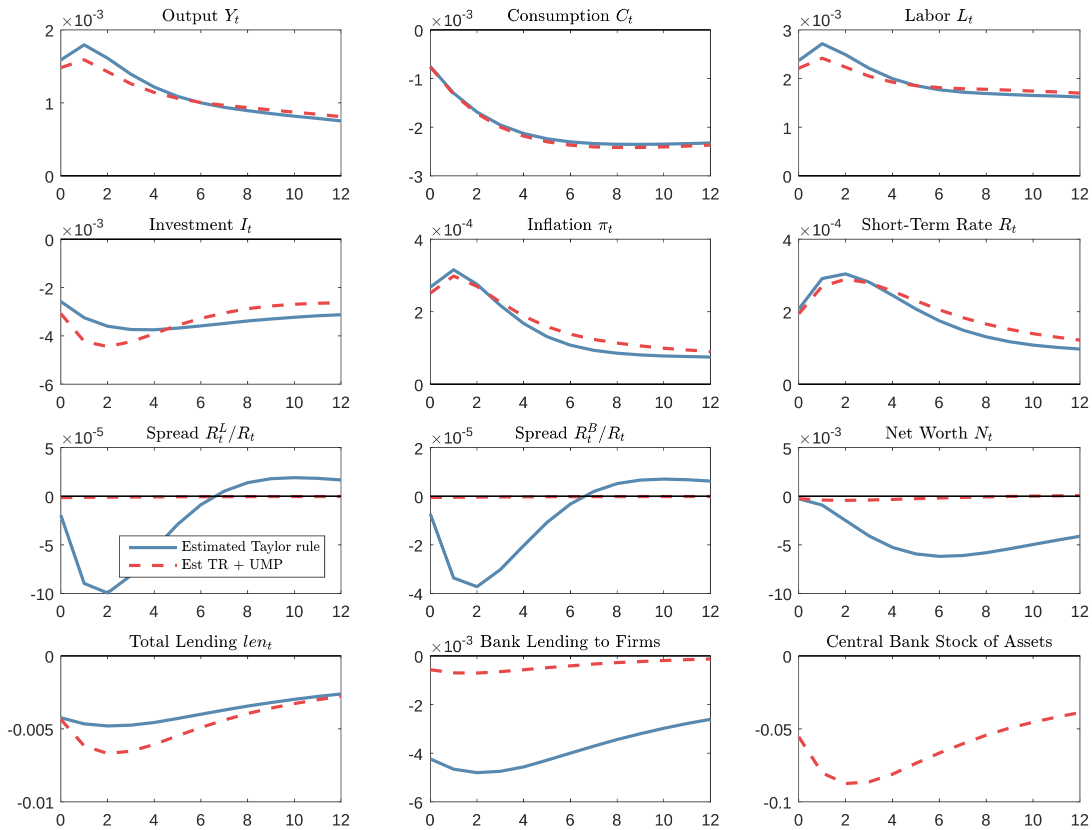


NOTE: The impulse responses are computed after taking a second order approximation to the equilibrium conditions of the model.

a consumption boom and higher inflation, but lower investment and GDP. Financial accelerator effects are very small, and hence there is not much that the central bank can do by using UMP. When UMP is deployed, it does not really affect the behavior of main variables, including consumption and hours, in a significant way.

Finally, we present the effects of a government spending shock (Figure 7). This shock does not increase government debt because lump-sum taxes adjust to keep debt constant. The effects of this shock are quite standard, and the introduction of financial frictions does not alter its effects. Specifically, the increase in government spending increases GDP and labor demand, but it crowds out consumption and investment. Inflation and short-term interest rates increase. The decline in investment leads to a reduction in lending, which in turn translates into lower spreads, and reduces banks' net worth. When UMP is deployed, the effect is mostly felt on financial variables: spreads

Figure 7: Impulse Response to a Government Consumption Shock



NOTE: The impulse responses are computed after taking a second order approximation to the equilibrium conditions of the model.

and bank capital are almost fully stabilized. However, the reaction of macroeconomic variables, and in particular the reaction of consumption and labor are extremely similar, which explains the small effect of UMP on welfare under demand shocks.

6.2 Using Alternative Monetary Policy Rules

We have analyzed the role of UMP when monetary policy is conducted according to the estimated Taylor rule. Next, as a robustness exercise, we look at what happens when monetary policy follows two types of more optimal rules: (i) a strict inflation targeting rule, and (ii) a policy aiming at targeting price and wage inflation. This way we can evaluate if there is a role for UMP when conventional monetary policy is conducted in a more optimal way. The results are presented in

Tables 9 and 10.

Table 9: Optimal UMP Policy, Strict Inflation Targeting

Shocks	Policy	ρ_Ψ	γ_Ψ	$\mathbb{W}_t$	C.E. (in %)
All	Corp., $\bar{R}^L_t - R_t$	0.14	9.62	-553.83	1.45
Demand	Gov., $R^B_t - R_t$	0.84	1000000	-576.16	0.31
Supply	All	0	0	-553.67	0
Financial	Gov., $\bar{R}^L_t - R_t$	0.97	9163.7	-575.74	1.18

Under strict inflation targeting, the results are virtually unchanged: UMP matters and the welfare gains are exactly the same as under the estimated rule: 1.45 percent of lifetime consumption. These gains are still most important under financial shocks. However, under a strict inflation targeting two new results appear. First, the optimal UMP under supply shocks is to not use it. Under the six possible alternatives, the coefficients are always zero. Second, with demand shocks, the welfare gains are slightly higher than under the estimated rule.

As a final robustness check, we study what happens under an optimized Taylor rule that targets both price and wage inflation. Since the model has price and wage stickiness, a Taylor rule that targets both price and wage inflation is optimal (see Erceg, Henderson and Levin, 2000).[14] We find that in the estimated model, the optimized Taylor rule takes the form of

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\gamma_R} \left(\frac{\pi_t}{\pi}\right)^{\gamma_\Pi(1-\gamma_R)} \left[\frac{\left(\tilde{W}_t/\tilde{W}_{t-1}\right)\exp(\Lambda_t)}{\exp(\Lambda)}\right]^{\gamma_W(1-\gamma_R)} \exp(\varepsilon_{m,t})$$

where $\gamma_R = 0.00$, $\gamma_\Pi = 23403.33$, and $\gamma_W = 7784.26$.

In this case, the welfare improvements from using unconventional monetary policies become even smaller. In fact, when all shocks are taken into account, the optimal unconventional policy is to not intervene. However, when the optimality of UMP is studied under a subset of shocks, then it is still optimal to deploy it under demand or financial shocks, but the effects are substantially lower than under the estimated Taylor rule or the strict inflation targeting rule.

[14] We also studied optimized Taylor rules that include output growth, but found that the optimal response to that variable is 0.

Table 10: Optimal UMP Policy, Price and Wage Inflation Targeting

Shocks	Policy	ρ_Ψ	γ_Ψ	$\mathbb{W}_t$	C.E. (in %)
All	All	0	0	-554.49	0
Demand	Corp., $\bar{R}_t^L - R_t$	0.03	19128.8	-577.02	0.09
Supply	All	0	0	-553.67	0
Financial	Gov., $\bar{R}_t^B - R_t$	0	1.39	-580.25	0.17

To conclude, in this section we have shown that if monetary policy is conducted under a standard, estimated Taylor rule, then including a second policy instrument in the form of unconventional monetary policy can have sizable welfare effects, specially when the economy is hit by financial shocks. This result still holds when the central bank follows a strict inflation targeting rule with conventional monetary policy. Under a rule that targets price and wage inflation, the welfare effects are much smaller.

7 Conclusions

In this paper, we have examined if the Fed should keep UMP in place once interest rates normalize, in a model with a banking sector that engages in maturity transformation and which is estimated using nonlinear techniques. We have studied one particular aspect of UMP: asset purchases of government and corporate bonds. We have found that the answer is yes: there are welfare benefits from using these policies to address the effects of financial shocks, to the economy. However, this main result comes with a few caveats. We have also found that under more traditional supply and demand shocks, the benefits of using UMP are much smaller. In this paper, we have made no attempt to quantify the possible costs of introducing UMP, such as less efficient intermediation by the central bank, and interactions with fiscal policy stemming from central bank losses. It is quite likely that UMP should not be used under supply shocks, given its small benefits in this case. We have also found that providing credit to the private sector or purchasing government bonds has very similar effects to the economy. But, if purchases of government bonds entail lower (or no costs) compared to a policy of direct lending to the private sector, then the former policy will be preferable to the latter.

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