IIMB-WP No. 652/2021

WORKING PAPER NO: 652

Conventional vs. Unconventional Monetary Policy under Financial Repression

Ankit Kumar
Assistant Professor of Economics
Indian Institute of Management Vishakapatnam
Andhra Bank School of Business Building Road,
Chinna Waltair, Andhra University,
Visakhapatnam, Andhra Pradesh – 530 003
ankitk@iimv.ac.in

Rahul Rao
Doctoral Student
Economics & Social Sciences
Indian Institute of Management Bangalore
Bannerghatta Road, Bangalore – 560 076
rahul.rao18@iimb.ac.in

Chetan Subramanian
Professor
Economics & Social Sciences
Indian Institute of Management Bangalore
Bannerghatta Road, Bangalore – 560 076
chetan.s@iimb.ac.in

Year of Publication – November 2021

Conventional vs. Unconventional Monetary Policy under Financial Repression

Ankit Kumar * Rahul Rao† Chetan Subramanian‡

November 2, 2021

Abstract

We extend a simple Dynamic Stochastic General Equilibrium (DSGE) model with segmented financial markets to include financial repression and examine its impact on the transmission of conventional and unconventional monetary policies. In our model, financial repression arises as the government forces banks to hold a fraction of their assets in government debt. We show that such distortions can invert monetary transmission under quantitative easing (QE) policy: an expansionary QE program raises term premiums on corporate bonds and causes a contraction instead of an expansion in the economy. Such perversion is absent under conventional policy. Further, in contrast to the literature Carlstrom et al. (2017), we show that a simple Taylor rule welfare dominates a term premium peg under financial shocks while the peg does better in the case of non-financial shocks.

Keywords: Financial Repression, Segmented Asset Markets, Quantitative easing, Term Premium targeting, Leverage constraint.

JEL codes: E22, E31, E43, E44, E52, E58.

*Assistant Professor, Economics Area, Indian Institute of Management, Vishakapatnam (email: ankitk@iimv.ac.in)

†*Corresponding Author:* PhD Student, Economics & Social Sciences Area, Indian Institute of Management, Bangalore - 560076 (email: rahul.rao18@iimb.ac.in)

‡Professor, Economics & Social Sciences Area, Indian Institute of Management, Bangalore (email: chetan.s@iimb.ac.in)

1. Introduction

This paper aims to examine the efficacy of QE programs vis-à-vis conventional monetary policy in the presence of financial repression. Post 2008, quantitative easing (QE) – the large-scale purchases of assets by central banks – has become an essential weapon in the arsenal of central banks worldwide. Indeed, in the aftermath of the pandemic, many emerging markets emulated their developed peers with bond-buying programs to mitigate the fallout to the financial sector from the crisis. Much of the literature has found QE policies effective, particularly when the interest rate is constrained by the zero lower bound Bernanke (2020). However, the literature is silent on the effectiveness of these programs in the presence of financial repression.

Financial repression is a term generally used to refer to a wide array of government policies employed to divert resources from the rest of the economy to the government. Reinhart and Sbrancia (2015) provide evidence to suggest that governments have extensively used financial repression in the post World War-II era to borrow at cheap rates, particularly during times of distress. Here, we focus on a particular form of repression imposed by the government, which requires banks to hold a certain fraction of their assets as government debt. Our objective is to illustrate the consequences of these distortions on the monetary transmission mechanism under QE and contrast it with conventional policy.

Our model is a simple extension of Sims and Wu (2020). Asset markets are segmented because only financial intermediaries can purchase long-term debt issued by the government and the firms. Firms issue long-term debt to finance part of their investment expenditure. Households can access long-term debt only indirectly by depositing their funds in financial intermediaries. As in Sims and Wu (2020), a simple agency problem results in an endogenous leverage constraint that limits the financial intermediary's ability to arbitrage the yield gap between the short-term deposit rate and long-term lending rate, resulting in a time-varying term premium.

We follow Chari et al. (2020)[1] and assume that banks face a "regulatory constraint" which requires them to hold a certain fraction of their assets as government debt. This financial repression reduces the yield on long-term government bonds and offsets their

[1] See also Kriwolutzy et al. (2018)

term premiums. In the milieu, we study the impact of conventional and unconventional (QE) monetary policies. Our model's conventional monetary policy involves the central bank setting short-term interest rates on reserves according to the Taylor rule. Unconventional or QE policy, on the other hand, involves the central bank buying or selling long-term government bonds.

We begin by comparing exogenous shocks to unconventional policy and conventional policies. Consider, first, the case of an expansionary QE shock, which involves increasing government bond-buying by the central bank. We show that financial repression can completely invert the monetary transmission mechanism: the expansion in the central bank's balance sheet can raise the term premiums on private bonds and cause a contraction instead of an expansion in the economy. The intuition is best understood by noting that such a program has opposing effects on the leverage and the regulatory constraints.

While the bank's reduced holdings of government bonds eases the agency problem and relaxes the leverage constraint, it tightens the regulatory constraint. Effectively, the binding regulatory constraint implies limited substitutability between government and private bonds. Banks are forced to keep loans to the private sector and the government in fixed proportions. As the regulatory constraint tightens on the banks due to the central bank's bond-buying program, banks respond by rebalancing their portfolio. They reduce their loans to the private sector, which causes the term premiums to rise on private bonds.

By contrast, a cut in the policy rate (conventional monetary policy shock) causes an expansion in the economy. The lower policy rate by increasing the net worth relaxes the leverage constraint and increases investment demand. However, the consequent rise in demand for private bonds tightens the regulatory constraint, putting upward pressure on the term premiums. Ultimately, the absence of a strong portfolio rebalancing effect results in the net worth effect dominating, causing a lowering of the term premiums on private bonds and an expansion in the economy.

We next study the monetary transmission mechanism under credit and productivity shocks in two different policy scenarios: (1) simple Taylor rule, and (2) term premium peg in which the central bank endogenously adjusts its bond portfolio to hold the term premium fixed. Further, we go on to welfare rank these rules under the two shocks. Our objective is to see how well the endogenous QE policy (term premium peg) performs relative to the Taylor rule.

An adverse financial or credit shock tightens the leverage constraints on financial intermediaries, causing term premiums to rise. The central bank responds under a term premium peg by purchasing government bonds to mitigate this rise. Lower government bond holdings, in turn, cause the regulatory constraint to tighten, and the financial intermediary rebalances its portfolio by lowering its holding of private bonds. Consequently, term premiums on corporate bonds rise, and investment and output in the economy drop. On the other hand, the absence of the strong portfolio rebalancing effect in the simple Taylor rule causes it to welfare dominate the term premium peg.

Next, consider the case of a positive productivity shock. The rising net worth under this shock relaxes the leverage constraint and causes the term premiums to fall. Under a term premium peg, the central bank responds by selling government bonds to the intermediary, which relaxes the regulatory constraint. The relaxation of both the leverage and the regulatory constraints causes a more significant rise in investment and output relative to the Taylor rule. Consequently, the pegging rule ends up being welfare superior. Essentially, unlike the term premium peg, the absence of the central bank selling bonds in the case of Taylor rule tightens the regulatory constraint, thereby limiting investment, output, and hence welfare.

The work in this paper straddles several strands of literature. A significant body of work has tried to understand the differences in transmission of conventional versus unconventional monetary policy. Conventional policy entails the use of short-term interest to influence aggregate demand via its impact on the long-term interest rate, exchange rates, asset prices, bank lending Kashyap et al. (1994) and the credit channel Bernanke and Gertler (1995). Quantitative easing, on the other hand, involves changing the size and the composition of central bank balance sheets to alter the yield curve. Theoretically, medium- to long-term expected interest rates are a function of the investors' expectations of short-term rates. If assets are perfect substitutes, then arbitrage will mean that all assets have equal expected returns. Essentially, a bond-buying QE program that attempts to lower the long rate without changing investors' expectations about the short rates would leave the yield curve essentially unchanged as investors would arbitrage away the difference in yields.

Theoretically, financial segmentation resulting in imperfect substitutability between assets has been used by the literature to resolve this issue and explain the impact of QE on the real economy[2]. One way to introduce this imperfect substitutability is through employing the "preferred habitat" framework, where segmentation occurs due to investors' preferences for specific types of assets. Ray et al. (2019) incorporates the preferred habitat framework of Vayanos and Vila (2009) into a New Keynesian model to study QE. Alternatively, papers by Gertler and Karadi (2011, 2013); Carlstrom et al. (2017); Darracq Pariès and Kühl (2017); Harrison (2017); Sims and Wu (2019, 2020) incorporate segmented asset markets arising due to financial frictions in DSGE models to analyze the real effects of unconventional monetary policy.

As pointed out earlier, much of this literature has argued that unconventional policy has been quite effective in easing financial conditions, especially when interest rates have been constrained by the lower bound. In particular, when compared to conventional policy, QE is an effective tool to offset the negative impact of financial shocks. For instance, Carlstrom et al. (2017) show that an endogenous QE policy that directly targets the term premium completely sterilizes the real economy from shocks originating in the financial sector. Karadi and Nakov (2021) show, in a model of occasionally binding constraints, that the nature of the shock matters for the effectiveness of QE: these policies, while effective in the case of financial shocks, are ineffective when the economy is faced with non-financial shocks. Our work in this paper complements this literature and examines the effectiveness of QE policy when an economy under financial repression is faced with financial and non-financial shocks. In contrast to the literature, we show that QE exacerbates the effects of financial shocks on the economy when compared to a simple Taylor rule. At the same time, it mitigates the impact of non-financial shocks.

Our work is also closely related to Lahiri and Patel (2016), who, in a simple model, show that the presence of repression can invert monetary policy transmission under conventional policy. The result essentially arises due to the absence of net worth effects in their model. By contrast, we show that their result is overturned with a leverage constraint and consequent net worth effects.

Finally, this paper is related to the literature that examines the impact of financial repression on the economy. Recent work on this line includes Chari et al. (2020), which

[2] see Kuttner (2018) for an excellent survey.

shows that financial repression can be optimal if governments cannot credibly commit to paying back their debt. Kriwolutzy et al. (2018) use a framework similar to ours to quantify the extent of financial repression in the US during the post-WWII period. Our work adds to this literature and examines how financial repression deferentially impacts monetary policy transmission under conventional and unconventional monetary policy.

The rest of the paper is structured as follows: Section 2 outlines the model, Section 3 examines the impulse responses to conventional and unconventional monetary policy shocks, Section 4 contrasts welfare under the Taylor rule and a term premium peg and Section 5 concludes the paper. Detailed derivations of the model and steady state are provided in the Appendix.

2. Model

The model we use is a variant of Sims and Wu (2020) to highlight the effect of financial repression on the monetary transmission process under both conventional and unconventional policy. The economy consists of households, various production firms, financial intermediaries, fiscal authority, and a central bank. Households consume a composite final good, supply labor, and save in the form of one-period deposits. Asset markets are segmented in the sense that households cannot hold long-term bonds. A representative wholesale firm purchases labor from households and new capital from the capital goods firms. The firm must issue long-term bonds to finance part of its investment. The wholesale producer sells their output to a continuum of monopolistically competitive retailers who repackage it and sell it to the final goods firms.

Financial intermediaries use their net worth and deposits to purchase long-term bonds issued by firms and the government. These intermediaries are faced with two types of constraints. The first is an endogenous leverage constraint that arises due to a simple hold-up problem that constrains the amount of deposits that a given level of net worth can support. To the extent that intermediaries are leverage constrained, they cannot arbitrage the yield gap between short-term and long-term rates. The second constraint captures financial repression, termed the regulatory constraint, which forces banks to hold a fraction of their assets in the form of government bonds. The presence of this constraint drives a wedge between the return on private and government bonds.

Finally, there is a central bank which in addition to setting the short-term interest rate can also influence liquidity conditions by buying long-term bonds from financial intermediaries.

2.1 Households

There is a representative household which consumes final good, supplies labor to wholesale firm, and makes deposits with the financial intermediaries. Its preference over consumption and labor has the following form:

$$U_t = \mathbb{E}_t \sum_{i=0}^{\infty} \beta^i \left\{ ln(C_{t+i} - hC_{t+i-1}) - \chi \frac{L_{t+i}^{1+\eta}}{1+\eta} \right\}$$

where $0 < \beta < 1$ is the household's utility discounting factor, $0 < h < 1$ is the habit persistence parameter, and $\chi, \eta > 0$ are the relative utility of labor and inverse of Frisch elasticity of labor supply, respectively.

The deposits are made in the form of one-period nominal debt bonds D_t so that the household has the option of deciding whether to roll-over the deposits or not. These bonds earn a gross return of R_t^D in the next period $(t+1)$.

The household earns labor income W_t, dividends DIV_t from their ownership in production firms and intermediaries and pays a lump-sum tax T_t to the government. Formally, the budget constraint of the household can be written as:

$$P_t C_t + D_t = W_t L_t + R_{t-1}^D D_{t-1} + DIV_t - P_t X - P_t T_t$$

Here, P_t is the price of final output good and X is the amount of fixed real equity (in terms of consumption units) infused by household to start up new intermediaries each period.

The first order conditions with respect to C_t, L_t, and D_t respectively are:

$$\mu_t = \frac{1}{C_t - hC_{t-1}} - \beta h \mathbb{E}_t \frac{1}{C_{t+1} - hC_t} \tag{1}$$

$$\chi L_t^{\eta} = \mu_t w_t \tag{2}$$

$$1 = R_t^D \mathbb{E}_t[\Lambda_{t,t+1} \Pi_{t+1}^{-1}] \tag{3}$$

Here, $\mu_t = U'(C_t)$ is the real marginal utility of consumption, w_t is the real wage, $\Lambda_{t,t+1} = \beta \frac{\mu_{t+1}}{\mu_t}$ is the real stochastic discount factor of the household, and $\Pi_{t+1} = \frac{P_{t+1}}{P_t}$ is the gross inflation rate. Together, equations (1)-(2) give us the households labor supply curve while equation (3) is the familiar Fisher equation.

2.2 Financial Intermediaries

There is a unit mass of intermediaries (indexed by i) in the economy. Each period, a fraction $1 - \sigma$ of total intermediaries stochastically exit and return their net worth to their owner household. They are replaced by an equal number of new intermediaries with start-up equity of X given to them by the household.

On its asset side, each intermediary holds perpetual government ($B_{i,t}$) and wholesale firm's ($F_{i,t}$) debt bonds along with the reserves $RE_{i,t}$ (issued by the Central Bank)[3]. It finances them using one-period deposits ($D_{i,t}$) from households and its own net worth ($N_{i,t}$). The balance sheet equation of an intermediary i is given by:

$$Q_t F_{i,t} + Q_{B,t} B_{i,t} + RE_{i,t} = D_{i,t} + N_{i,t} \tag{4}$$

Until an intermediary stochastically exits, it accumulates its net worth instead of paying it out as dividends to the households. Therefore, its net worth evolves according to:

$$N_{i,t} = (R_t^F) Q_{t-1} F_{i,t-1} + (R_t^B) Q_{B,t-1} B_{i,t-1} + (R_{t-1}^{re}) RE_{i,t-1} - R_{t-1}^D D_{i,t-1}$$

where $R_t^F = \frac{1+\kappa Q_t}{Q_{t-1}}$, $R_t^B = \frac{1+\kappa Q_{B,t}}{Q_{B,t-1}}$ are the realized holding period returns on private and government bonds, respectively and (R_{t-1}^{re}) is the gross interest rate on reserves set by the central bank which is known at time $t-1$. Combining the above equation with (4), we get:

$$N_{i,t} = (R_t^F - R_{t-1}^D) Q_{t-1} F_{i,t-1} + (R_t^B - R_{t-1}^D) Q_{B,t-1} B_{i,t-1} + (R_{t-1}^{re} - R_{t-1}^D) RE_{i,t-1} + R_{t-1}^D N_{i,t-1} \tag{5}$$

[3] The reserves are one-period nominal debt bonds like household deposits and pay gross return of R_t^{re} in period $t+1$.

The interpretation of the above equation is standard. The first three terms represent the excess returns over the deposit rate of holding private bonds, government bonds, and reserves. The last term reflects the savings from financing using net worth as opposed to deposits. The stochastic exit assumption prevents an intermediary from accumulating enough net worth to make the limited enforcement constraint that we describe below redundant.

The presence of excess returns implies that the objective of a financial intermediary is to maximize the expected terminal value of its net worth. The expected continuation value of remaining an intermediary at the end of period t is given by:

$$V_{i,t} = (1-\sigma)\mathbb{E}_t[\Lambda_{t,t+1} n_{i,t+1}] + \sigma\mathbb{E}_t[V_{i,t+1}\Lambda_{t,t+1}] \tag{6}$$

where $V_{i,t}$ is the maximized expected value of the intermediary's terminal net worth, $n_{i,t+j} = \frac{N_{i,t+j}}{P_{t+j}}$ is the real net worth at $t+j$ and $\Lambda_{t,t+j}$ is the real stochastic discount factor of households.

The financial intermediary faces two constraints. The first as in Gertler and Karadi (2011), arises due to an agency problem under which an intermediary can divert a fraction θ_t of the total value of private debt bonds and $\Delta\theta_t$ fraction of the government debt bonds, where $\theta_t \geq 0, \Delta \leq 1$. This means that it is easier for the intermediary to divert private bonds than government bonds. Creditors can recover the rest of the intermediary's assets including reserves which are held with the central bank. As a consequence of this agency problem, the following endogenous leverage constraint must be satisfied for depositors to be willing to lend to intermediaries:

$$V_{it} \geq \theta_t(Q_t f_{i,t} + \Delta Q_{B,t} b_{i,t}) \tag{7}$$

where $f_{i,t}$ and $b_{i,t}$ are the real values of private and government bonds, respectively. Here, the left-hand side denotes the expected value of continuing as an intermediary after time t, and the right-hand side denotes the gain if it decides to divert assets. The constraint ensures that it is never optimal for the intermediary to abscond with assets. It also implies that its net worth limits the intermediary's ability to attract deposits.

The second constraint faced by the intermediaries is a regulatory constraint. Following Chari et al. (2020), financial intermediaries face an additional constraint wherein they have to hold a certain minimum fraction (Γ_t) of their bond assets in the form of government bonds. Formally, the constraint is given by

$$Q_{B,t}b_{i,t} \geq \Gamma_t(Q_{B,t}b_{i,t} + Q_t f_{i,t})$$

which can be rewritten as

$$Q_{B,t}b_{i,t} \geq \gamma_t Q_t f_{i,t} \tag{8}$$

where $\gamma_t = \frac{\Gamma_t}{1-\Gamma_t}$.

The objective of an intermediary is to maximize equation (6) subject to equations (5), (7) and (8). The optimization yields the first order conditions:

$$\mathbb{E}_t[\Lambda_{t,t+1}\Pi_{t+1}^{-1}\Omega_{i,t+1}(R_t^{re} - R_t^D)] = 0 \tag{9}$$

$$\mathbb{E}_t[\Lambda_{t,t+1}\Pi_{t+1}^{-1}\Omega_{i,t+1}(R_{t+1}^F - R_t^D)] = \frac{\lambda_{it}}{1+\lambda_{it}}\theta_t + \frac{\zeta_{it}}{1+\lambda_{it}}\gamma_t \tag{10}$$

$$\mathbb{E}_t[\Lambda_{t,t+1}\Pi_{t+1}^{-1}\Omega_{i,t+1}(R_{t+1}^B - R_t^D)] = \frac{\lambda_{it}}{1+\lambda_{it}}\theta_t\Delta - \frac{\zeta_{it}}{1+\lambda_{it}} \tag{11}$$

where ($\Omega_{i,t+1} = 1 - \sigma + \sigma\frac{\partial V_{it+1}}{\partial n_{i,t+1}}$). The Lagrange multipliers λ_{it} and ζ_{it} represent the tightness of enforcement (or incentive) and regulatory constraints, respectively. Equation (9) implies intermediaries do not earn any excess returns on the reserves and ($R_t^{re} = R_t^D$). Equations (10) and (11) imply that if the leverage constraint is binding ($\lambda_{it} > 0$), then excess returns earned on both private and government bonds persist in equilibrium. We note from (10) that the presence of the regulatory constraint drives a wedge between the expected returns on private and government bonds. Intuitively, such a constraint raises the demand for government bonds and depresses its yield. To see this, consider the case when there is no repression. Under this scenario, the regulatory constraint is slack i.e. ($Q_{B,t}b_{i,t} > \gamma_t Q_t f_{i,t}$) and $\zeta_{it} = 0$. Equation (11) can therefore be written as

$$\mathbb{E}_t[\Lambda_{t,t+1}\Pi_{t+1}^{-1}\Omega_{i,t+1}(\tilde{R}_{t+1}^B - R_t^D)] = \frac{\lambda_{it}}{1+\lambda_{it}}\theta_t\Delta \tag{12}$$

where, $\tilde{R}_{t+1}^B$ denotes the laissez-faire return on government bond. To see the impact of financial repression, we combine equations (11) and (12) to get

$$\mathbb{E}_t[\Lambda_{t,t+1}\Pi_{t+1}^{-1}\Omega_{i,t+1}(R_{t+1}^B - \tilde{R}_{t+1}^B)] = -\frac{\zeta_{it}}{1+\lambda_{it}}$$

It follows from the above equation that whenever the regulatory constraint binds ($\zeta_{it} > 0$), the return on government bond is lesser than the laissez-faire case, i.e. $R_{t+1}^B < \tilde{R}_{t+1}^B$. Throughout the paper, we assume that the regulatory constraint binds. The extent of the financial repression varies with time due to changing economic conditions which affect the tightness of constraint.

We also assume that the leverage constraint always binds. Following Sims and Wu (2020), we assume that value function is linear in net worth, i.e., $V_{it} = a_t n_{it}$. Defining $\phi_{it} = \frac{Q_t f_{it} + \Delta Q_{B,t} b_{it}}{n_{it}}$ as the modified leverage ratio for an intermediary and solving for ϕ_t, we get

$$\phi_t = \frac{(1+\Delta\gamma_t)\mathbb{E}_t[\tilde{\Lambda}_{t,t+1}R_t^D]}{\theta_t + \theta_t\Delta\gamma_t - \mathbb{E}_t[\tilde{\Lambda}_{t,t+1}\{(R_{t+1}^F - R_t^D) + \gamma_t(R_{t+1}^B - R_t^D)\}]}$$

where $\tilde{\Lambda}_{t,t+1} = \Lambda_{t,t+1}\Pi_{t+1}^{-1}\Omega_{t+1}$.

Note that the leverage ratio decreases with increasing θ_t. Intuitively, a higher θ_t means intermediary can divert a larger fraction of the assets and hence the depositor will require the intermediary to put in more equity. On the other hand, higher expected excess returns $(R_{t+1}^F - R_t^D)$ or $(R_{t+1}^B - R_t^D)$ results in a higher leverage ratio. Intuitively, higher expected excess returns on assets increases expected net worth of the intermediary and reduces risk of default. Similarly, the discounted deposit rate $\mathbb{E}_t[\tilde{\Lambda}_{t,t+1}R_t^D]$ increases the net worth and hence raises the continuation value of staying a banker. Thus, it also impacts the leverage ratio positively.

The presence of both leverage and regulatory constraints results in a term premium in the model. Following Carlstrom et al. (2017), we define (log) term premium as the difference between the observed (log) yield on a long term bond[4] and the corresponding (log) yield implied by applying the expectation hypothesis (EH) of the term structure to the series of short rates. The price of such a hypothetical (EH) bond satisfies

---

[4]in our quantitative analysis, one period is one quarter and we consider $(1-\kappa)^{-1} = 40$, which means that the long-term bond is actually a 10-year bond.

$$R_t^D = \frac{1 + \kappa Q_{t+1}^{EH}}{Q_t^{EH}}$$

and its yield is given by

$$R_t^{EH} = \frac{1}{Q_t^{EH}} + \kappa$$

The yield of a long bond is given by

$$RL_t^i = \frac{1}{Q_{i,t}} + \kappa \; ; \; i \in \{B, F\}$$

We define term-premium as the ratio of these two yields, i.e,

$$TP_{i,t} = \frac{RL_t^i}{R_t^{EH}} \; ; \; i \in \{B, F\} \tag{13}$$

It follows from equations (10), (11) and (13) that the term-premium on private and government bonds is a function of the asset market segmentation, financial repression and the credit shocks. This insight turns out to be crucial when analyzing monetary policy transmission.

2.3 Production

Our production section is similar to Sims and Wu (2020) which consists of four different types of production firms: a competitive final good producer, monopolistic retailers, wholesale firm and investment good firm. A representative investment good firm produces new physical capital from final output subjecting to a convex adjustment cost. The key departure from a standard framework is the wholesale firm which produces output using its own capital which is accumulated via purchase of new capital from the investment good firm, and labor hired from labor unions. A continuum of retail firms then repackages this wholesale output for resale to the final good firm. These retail firms behave as monopolistic competitors and are subject to price stickiness. We focus on the wholesale firm in the text, while rest of the production section is detailed in Appendix B.

The wholesale firm produces output using labor input $L_{d,t}$ and the capital that it accumulates using a Cobb-Douglas technology:

$$Y_{w,t} = A_t(u_t K_t)^{\alpha} L_{d,t}^{1-\alpha}$$

where A_t is an exogenous productivity variable that obeys an exogenous stochastic process. K_t is the stock of physical capital, which the firm owns and u_t is the capital utilization factor. Also, $\alpha \in (0,1)$ is exponent on capital services in the production.

Physical capital accumulates according to the following law of motion, which generates faster depreciation as cost of utilization:

$$K_{t+1} = \hat{I}_t + (1 - \delta(u_t))K_t \tag{14}$$

Here, $\delta(u_t) = \delta_0 + \delta_1(u_t - 1) + \frac{\delta_2}{2}(u_t - 1)^2$ is the utilization adjustment cost, which maps utilization into depreciation.

We assume that the wholesale firm purchases at least a constant fraction ψ of new physical capital $\hat{I}_t$ using fresh issues of perpetual bonds. This results in a "loan in advance" constraint of the form:

$$\psi P_t^K \hat{I}_t \leq Q_t CF_{w,t} = Q_t(F_{w,t} - \kappa F_{w,t-1}) \tag{15}$$

where P_t^K is the price of the new physical capital. $CF_{w,t}$ is the new bond issued which is the difference of total coupon liability $F_{w,t}$ from the past period, while Q_t is the nominal price of the bond. The labor is hired in competitive market at the nominal wage W_t. The firm maximizes the present discounted value of real dividend. The nominal dividend of the firm is given by:

$$DIV_{w,t} = P_{w,t}A_t(u_t K_t)^{\alpha} L_{d,t}^{1-\alpha} - W_t L_{d,t} - P_t^K \hat{I}_t - F_{w,t-1} + Q_t(F_{w,t} - \kappa F_{w,t-1})$$

The first order conditions are:

$$w_t = (1-\alpha)p_{w,t}A_t(u_t K_t)^{\alpha} L_{d,t}^{-\alpha} \tag{16}$$

$$\nu_{1,t}\delta^{'}(u_t) = \alpha p_{w,t}A_t(u_t K_t)^{\alpha-1} L_{d,t}^{1-\alpha} \tag{17}$$

$$\nu_{1,t} = (1 + \psi\nu_{2,t})p_t^k \tag{18}$$

$$p_t^k M_{1,t} = \mathbb{E}_t\Lambda_{t,t+1}\left[\alpha p_{w,t+1}A_{t+1}(u_{t+1}K_{t+1})^{\alpha-1}u_{t+1}L_{d,t+1}^{1-\alpha} + (1-\delta(u_{t+1}))p_{t+1}^k M_{1,t+1}\right] \tag{19}$$

$$Q_t M_{2,t} = \mathbb{E}_t\Lambda_{t,t+1}\Pi_{t+1}^{-1}[1 + \kappa Q_{t+1}M_{2,t+1}] \tag{20}$$

Here, $\nu_{1,t}$ and $\nu_{2,t}$ are the Lagrange multipliers for (14) and (15) respectively, and $M_{1,t} = 1 + \psi\nu_{2,t}$ and $M_{2,t} = 1 + \nu_{2,t}$ are two auxiliary variables. Variables w_t, $p_{m,t}$ and p_t^k are real wages, relative price of wholesale product and relative price of new capital, respectively. (16) is standard labor demand equation. The uniqueness lies with $M_{1,t}$ and $M_{2,t}$ which serve as endogenous "investment wedge" and "financial wedge", respectively. The fluctuations in these wedges are key channels through which any monetary action, either conventional or non-conventional, has impact on the real economy.

2.4 Fiscal Authority

There is a government which consumes a constant $\overline{G}$ amount of real output of final goods and makes the interest payments on its outstanding debt with the help of lump-sum tax raised from households, transfers from central bank and fresh issue of perpetual government bonds. The budget constraint is given by:

$$P_t\overline{G} + B_{G,t-1} = P_tT_t + P_tT_{cb,t} + Q_{B,t}(B_{G,t} - \kappa B_{G,t-1}) \tag{21}$$

where $B_{G,t-1}$ is the total coupon liability (payable at t) on outstanding bonds issued till $t-1$ and the last term is the amount of bonds freshly issued at t. Analogous to the case of private bonds, government bonds are perpertuities whose coupon rate decays at a rate of κ each period. $T_{cb,t}$ is the transfer from the central bank.

2.5 Central Bank

The central bank sets the interest rate on reserves according to the following Taylor Rule:

$$lnR_t^{re} = (1-\rho_r)lnR^{re} + \rho_r lnR_{t-1}^{re} + (1-\rho_r)[\phi_\pi(ln\Pi_t - ln\Pi) + \phi_y(lnY_t - lnY_{t-1})] + s_r\epsilon_{r,t}$$

where R^{re} and Π denote the steady state values of the policy rate and inflation respectively, with $0 < \rho_r < 1$, $\phi_\pi > 1$ and $\phi_y > 0$. Since $R_t^{re} = R_t^D$, setting the rate on reserves would be equivalent to the central bank setting the deposit rate. Below, we will also investigate the efficacy of putting the term premium in the Taylor rule.

The segmentation of the short-term market from the long-term bond market implies that the central bank can also conduct monetary policy by purchasing long-term government bonds. These purchases of government long-term debt, which we term as QE policies are financed using its reserves. Formally, the balance-sheet equation for the central bank is given by:

$$Q_{B,t}B_{cb,t} = RE_t$$

where $Q_{B,t}B_{cb,t}$ denotes the total value of all government bonds acquired by the central bank till period t, and RE_t denotes the nominal value of period t reserves issued by the central bank. QE policy involves purchase of long-term government debt by the central bank. We consider both exogenous and endogenous QE policies. For exogenous policy, we assume that the central bank bond holdings follow an exogenous AR(1) process:

$$b_{cb,t} = (1 - \rho_b)b_{cb} + \rho_b b_{cb,t-1} + s_b \epsilon_{b,t} \tag{22}$$

where b_{cb} denotes the steady state of government bond holdings and $\epsilon_{b,t}$ is an i.i.d shock. Endogenous QE policy considered in Section 4 involves the central bank pegging the government bond term premium to its steady state level, thus making the level of debt endogenous.

Finally, the monetary authority remits any net revenue it makes to the government in the form of lump-sum transfers $T_{cb,t}$. This can be expressed in real terms as

$$T_{cb,t} = (R_t^B - R_{t-1}^{re})\Pi_t^{-1}Q_{B,t-1}b_{cb,t-1}$$

where the right-hand side reflects the net revenue earned by the central bank on its asset holdings.

2.6 Aggregate and Market Clearing Conditions

Since the labor market is competitive, labor supplied by households should equal the labor demanded by the wholesale firm, i.e.

$$L_t = L_{d,t}$$

The market for long bonds of both wholesale firm and government should clear as follows:

$$f_{w,t} = f_t$$

$$b_{G,t} = b_t + b_{cb,t}$$

where f_t and b_t are the real aggregate values of all long bonds acquired by intermediaries from the wholesale firms and government, respectively.

Following (5), aggregate real net worth of intermediaries (both surviving and new ones) at the start of date t is given by:

$$n_t = \sigma\Pi_t^{-1}[(R_t^F - R_{t-1}^d)Q_{t-1}f_{t-1} + (R_t^B - R_{t-1}^d)Q_{B,t-1}b_{t-1} + (R_{t-1}^{re} - R_{t-1}^d)re_{t-1} + R_{t-1}^d n_{t-1}] + X \quad (23)$$

Since households own both financial and non-financial firms, so we plug back the aggregate real dividends from these firms and X from equation (23) into the budget constraint of households to get the aggregate resource constraint:

$$Y_t = C_t + I_t + G_t$$

3. Numerical Experiments

In this section, we carry out simple numerical exercises to investigate the impact of financial repression on monetary policy transmission under both conventional and unconventional policies. Parameters governing preferences and technology, and those related to financial intermediaries are taken from Gertler and Karadi (2011); Sims and Wu (2020). The unit of time is one quarter. The choice of loan in advance parameter $\psi = 0.61$ and the minimum fraction of government bonds in banks portfolio $\Gamma_t = 0.27, \ \forall t$, are both in line with Kriwolutzy et al. (2018). It means that intermediaries are mandated to hold at least 27 percent of their total assets value in the form of government bonds. All the parameters are listed in Table 1 and steady state calculations are shown in Appendix C.

3.1 Unconventional monetary policy shocks

We begin by considering impulse responses under an exogenous positive QE shock. The bond-buying program of the central bank is described by equation (22). Here, the vertical axes indicate deviations of the variables from steady-state, and the horizontal axes indicate time in quarters. Figure 1 shows that such a shock has opposing effects on the leverage and the regulatory constraints. The bond-buying program by the central bank increases the demand for government debt which tightens the regulatory constraint. The increased demand for government bonds raises its price and lowers its expected return.

Under a binding regulatory constraint, the financial intermediary must hold government and private bonds in a fixed proportion. The intermediary, therefore, responds to this shock by rebalancing their portfolio and reducing their holding of private bonds. In the spirit of Chari et al. (2020) and Kriwolutzy et al. (2018), this portfolio effect causes yields on private bonds to rise and investment to fall. On the other hand, QE increases the reserves intermediaries hold. Higher reserves, in turn, increase their net worth (see equation (4)) and relax the leverage constraint. The positive net worth effect causes deposits and stimulates investment. For our baseline parameters, the portfolio effect seems to dominate, resulting in reduced investment and output.

In an environment without the regulatory constraint, a positive shock to QE would increase banks' net worth and result in an expansion of production and investment in the economy. However, financial repression in the form of the regulatory constraint can completely invert the monetary transmission mechanism under QE: an increase in the bond-buying by the central bank raises the yield on private bonds and causes a contraction instead of an expansion in the economy.

3.2 Conventional Monetary Policy Shock

Figure 2 shows the impulse responses to a negative policy rate shock. Again, this conventional, expansionary policy shock has opposing effects on leverage and regulatory constraints. The reduction in the deposit rate raises excess returns earned by the intermediary on their assets, causing their net worth to rise (see equation (5)). The positive net worth effect relaxes the leverage constraint, increasing deposits and raising the demand for private bonds. The rise in demand for private bonds lowers their yield and stimulates investment.

Under financial repression, these intermediaries cannot increase their holdings of private bonds without proportionately raising their holdings of government bonds. This portfolio effect raises the price of government bonds and lowers their yields. In the end, it is the net worth effect that trumps, causing investment and output to rise.

4. Simple Rules

In this section, we illustrate the monetary transmission mechanism under credit and productivity shocks in two different policy scenarios: (1) under the simple Taylor rule, (2) under term premium pegging in which the central bank endogenously adjusts its bond portfolio to hold the government bond term premium fixed.

Further, we go on to welfare rank these rules under the two shocks. For each shock, we compute the lifetime utility and compare it with that under the steady state for welfare-based evaluation of the alternative policy regimes. We measure the welfare cost by the fraction ξ of non-stochastic steady state consumption stream that households would be willing to give up to be indifferent between the corresponding lifetime utility under the steady state and that under the alternative monetary policies. Formally, it means that the present discounted value of lifetime utility needs to be equalized across the two sequences of consumption and labor i.e.,

$$U((1-\xi)C, L) = \mathbb{E}[U(C_t^a, L_t^a)]$$

$$\Rightarrow \sum_t \beta^t \left[ln(1-\xi)(C-hC) - \chi \frac{(L)^{1+\eta}}{1+\eta} \right] = \mathbb{E} \sum_t \beta^t \left[ln(C_t^a - hC_{t-1}^a) - \chi \frac{(L_t^a)^{1+\eta}}{1+\eta} \right]$$

Here, $\{C, L\}$ are the constant steady state consumption and labor values, and $\{C_t^a, L_t^a\}$ correspond to the alternative policies. Solving for ξ, we get

$$\xi = 1 - exp[(1-\beta)(\mathbb{E}[W_t^a] - W^{ss})]$$

where W_t is the present discounted value of lifetime utility[5] at time t and W^{ss} is its steady state value. Note that $\xi > 0$ means the household needs to give up consumption under steady state if it wants to achieve same welfare as the alternative policy regime. However, $\xi < 0$ means that the household is better under alternative regime than the steady state.

4.1 Credit Shock

An adverse credit shock (Figure 3) magnifies the agency cost problem by increasing the assets that financial intermediaries can divert. Consequently, the leverage constraint tightens, raising the yields on government and private bonds. Under a term premium peg, the central bank responds by purchasing government bonds to lower the yields. It follows from equations (10) and (11) that in the absence of regulatory constraints ($\zeta_{it} = 0$), such a policy completely neutralizes credit shocks.

Intuitively, the purchase of government bonds under this regime relaxes the leverage constraint by changing the composition of the intermediary's assets from government bonds to reserves (see equation (7)). As shown in Carlstrom et al. (2017), the relaxation of the leverage constraint completely sterilizes the real economy from credit shocks. However, with financial repression ($\zeta_{it} \neq 0$), the purchase of bonds by the central bank tightens the regulatory constraint. The financial intermediary responds by rebalancing its portfolio and reducing its holding of private bonds. As a consequence of this portfolio effect, term premiums on private bonds rise, which causes investment and output to fall.

By contrast, under Taylor rule, the absence of a portfolio rebalancing effect relaxes the leverage constraint. Relative to the peg, the lower term premium on private bonds mitigates to some extent the impact of adverse credit shocks. As a result, the fall in investment and output is lesser under this regime. The comparison of welfare perfor-

[5] W_t can be recursively written as $W_t = ln(C_t - hC_{t-1}) - \chi\frac{L_t^{1+\eta}}{1+\eta} + \beta\mathbb{E}[W_{t+1}]$

mances of the term-premium peg relative to the simple Taylor rule vindicates the above discussion. Table 2 shows the simple Taylor rule welfare dominates the term premium peg.

Our results suggest that the presence of financial repression reduces the efficacy of a term premium targeting in countering credit shocks. As emphasized earlier, these results are in contrast to Carlstrom et al. (2017), who find the term premium peg to be welfare enhancing.

4.2 Productivity Shock

Figure 4 shows that a temporary rise in productivity by lowering marginal costs causes inflation to fall (see equation (B.1.3)). The central bank responds by reducing rates to stabilize inflation. As mentioned earlier, lower interest rates raise the financial intermediary's net worth by increasing the excess returns earned on their assets. The positive impact on net worth relaxes the intermediary's leverage constraint and raises their demand for private bonds. The increase in demand for private bonds raises their price, lowers the yield, and tightens the regulatory constraint.

Under a term premium peg, the central bank responds to the rising term premium by selling bonds. Such a policy relaxes the regulatory constraint enabling the intermediary to increase its purchase of private bonds and stimulate investment. Under a Taylor rule, the absence of the above central bank intervention means that the rise in investment and output is lower under this regime. Table 2, which welfare ranks the rules supports the intuition obtained from the impulse responses. The term premium peg outperforms a simple Taylor rule in the case of productivity shocks. This result is in contrast to those obtained in the case of a credit shock.

In the spirit of Poole (1970), our analysis suggests that the nature of the shock determines the choice of the monetary policy regime. In the presence of financial repression, the model prescribes adopting a term premium peg when productivity shocks are predominant and a simple Taylor rule when credit shocks are predominant.

Next, we examine the impact on welfare when we reduce the financial repression parameter. Table 3 indicates that our results are robust to this change – Taylor rule does better under credit shocks, while the term premium peg is superior under productivity shocks. Notice also that the reduction of the portfolio effect results in a marked improvement in the performance of the term premium peg under credit shocks and the Taylor rule under productivity shocks.

5. Conclusion

How does financial repression impact the transmission of monetary policy? We examine this question in the context of both conventional and unconventional monetary policies. Financial repression policies that force banks to hold a fraction of their assets in the form of government bonds drive a wedge between the return on government and private bonds. In such an environment, we show that monetary policy transmission is inverted under a quantitative easing program in contrast to Taylor rule. Essentially, an expansionary QE program while lowering the government bond yield tightens the regulatory constraint and raises the yield on private bonds. Consequently, investment falls, and the economy contracts.

We then compare the performance from a welfare perspective of an endogenous QE program that pegs the term premium with a simple Taylor rule. Our results indicate that the performance of the endogenous QE program depends on the nature of the shock impacting the economy. While such a program trumps the Taylor rule in productivity shocks, it fares poorly in case of credit shocks. While our results are intuitive, the work in this paper is mainly analytical. A natural extension of our analysis is to examine empirically the impact of unconventional monetary policy on term-premiums and term spreads under financial repression. This exercise would be particularly pertinent for emerging economies where financially repressive policies are widely prevalent. We leave this exercise to future research.

References

Bernanke, B. S. (2020). The new tools of monetary policy. *American Economic Review*, 110(4):943–83.

Bernanke, B. S. and Gertler, M. (1995). Inside the black box: the credit channel of monetary policy transmission. *Journal of Economic Perspectives*, 9(4):27–48.

Calvo, G. A. (1983). Staggered prices in a utility-maximizing framework. *Journal of Monetary Economics*, 12(3):383–398.

Carlstrom, C. T., Fuerst, T. S., and Paustian, M. (2017). Targeting long rates in a model with segmented markets. *American Economic Journal: Macroeconomics*, 9(1):205–42.

Chari, V., Dovis, A., and Kehoe, P. J. (2020). On the optimality of financial repression. *Journal of Political Economy*, 128(2):710–739.

Christiano, L. J., Eichenbaum, M., and Evans, C. L. (2005). Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy*, 113(1):1–45.

Darracq Pariès, M. and Kühl, M. (2017). The optimal conduct of central bank asset purchases. Bundesbank Discussion Paper.

Gertler, M. and Karadi, P. (2011). A model of unconventional monetary policy. *Journal of Monetary Economics*, 58(1):17–34.

Gertler, M. and Karadi, P. (2013). Qe 1 vs. 2 vs. 3...: A framework for analyzing large-scale asset purchases as a monetary policy tool. *International Journal of Central Banking*, 9(SUPPL. 1):5–53.

Harrison, R. (2017). Optimal quantitative easing. Bank of England Working Paper.

Karadi, P. and Nakov, A. (2021). Effectiveness and addictiveness of quantitative easing. *Journal of Monetary Economics*, 117:1096–1117.

Kashyap, A. K., Lamont, O. A., and Stein, J. C. (1994). Credit conditions and the cyclical behavior of inventories. *The Quarterly Journal of Economics*, 109(3):565–592.

Kriwolutzy, A., Muller, G., and Scheer, A. (2018). Financial repression in general equilibrium. In *Bundesbank Seminar, White Paper*.

Kuttner, K. N. (2018). Outside the box: Unconventional monetary policy in the great recession and beyond. *Journal of Economic Perspectives*, 32(4):121–46.

Lahiri, A. and Patel, U. R. (2016). Challenges of effective monetary policy in emerging economies. In *Monetary Policy in India*, pages 31–58. Springer.

Poole, W. (1970). Optimal choice of monetary policy instruments in a simple stochastic macro model. *The Quarterly Journal of Economics*, 84(2):197–216.

Ray, W. et al. (2019). Monetary policy and the limits to arbitrage: Insights from a new keynesian preferred habitat model. In *2019 Meeting Papers*, number 692. Society for Economic Dynamics.

Reinhart, C. M. and Sbrancia, M. B. (2015). The liquidation of government debt. *Economic Policy*, 30(82):291–333.

Sims, E. and Wu, J. C. (2020). Evaluating central banks' tool kit: Past, present, and future. *Journal of Monetary Economics*.

Sims, E. R. and Wu, J. C. (2019). The four equation new keynesian model. Technical report, National Bureau of Economic Research.

Vayanos, D. and Vila, J.-L. (2009). A preferred-habitat model of the term structure of interest rates. Technical report, National Bureau of Economic Research.

6. Figures and Tables

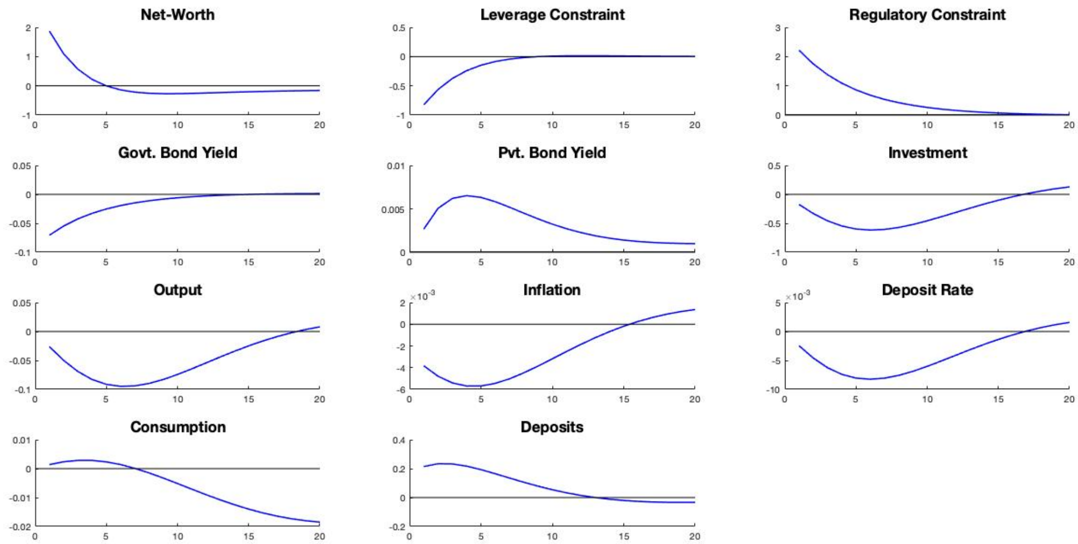

Figure 1: Impulse Responses to a positive QE shock

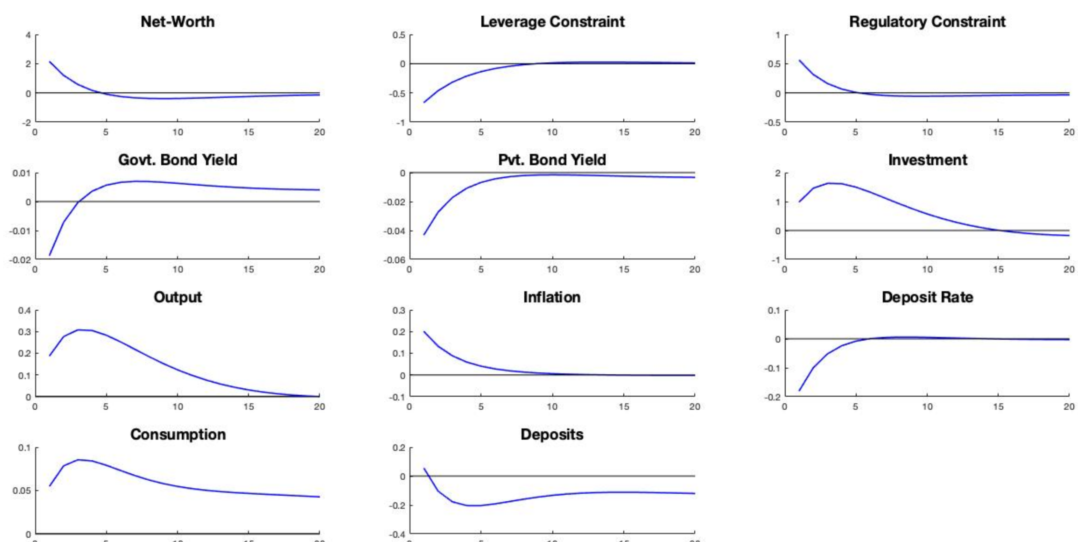

Figure 2: Impulse Responses to a negative policy rate shock

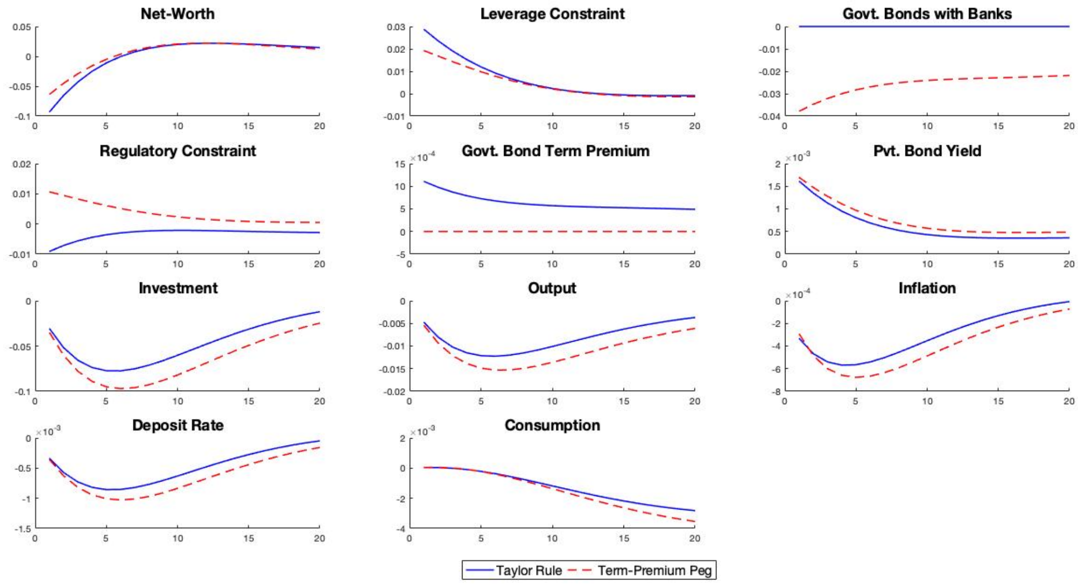

Figure 3: Impulse Responses to a positive credit shock under different monetary policy regimes

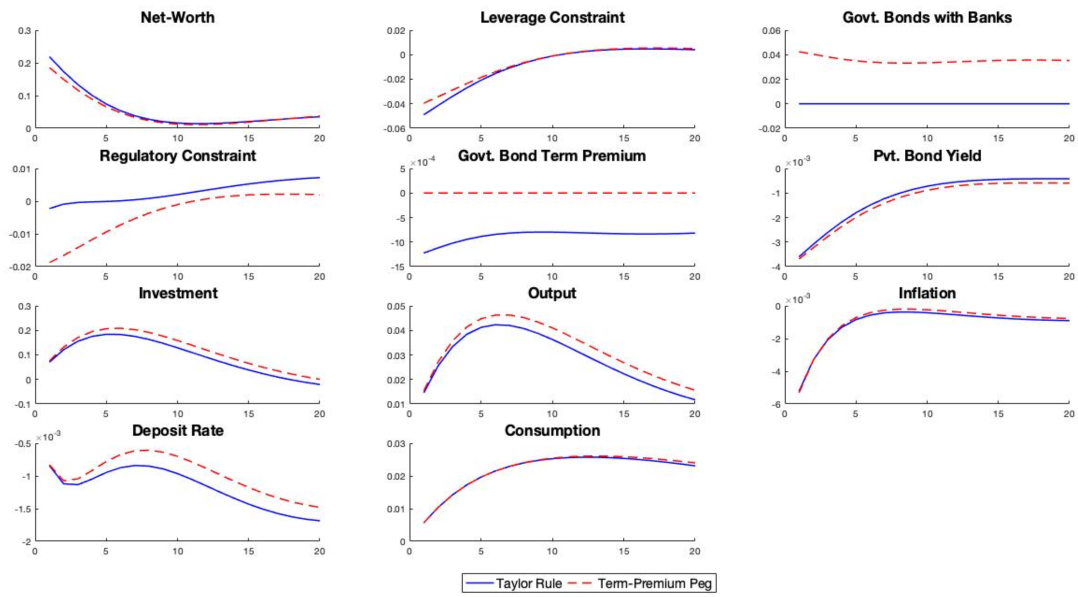

Figure 4: Impulse Responses to a positive productivity shock under different monetary policy regimes

Table 1: Parameters

Households		
β	0.995	Utility discount rate
h	0.815	Habit parameter
η	0.276	Inverse Frisch elasticity of labor supply
Financial Intermediaries		
σ	0.9	Survival rate
Δ	0.333	Relative moral hazard towards govt. bonds
Γ	0.27	Minimum fraction of govt. bonds in portfolio
ρ_θ	0.98	Persistence in variable θ_t
Wholesale Firm		
α	0.33	Effective capital share
U	1	Steady state capital utilization rate
δ_0, δ_2	0.025,0.01	Utilization adjustment-cost constants
ψ	0.61	Loan in advance parameter
κ	$1 - 40^{-1}$	Coupon decay parameter
ρ_A	0.95	Persistence in productivity process
Retail Firms		
ϵ_p	11	Elasticity of substitution
ϕ_p	0.75	Probability of keeping prices fixed
Investment Goods Producer		
κ_I	2	Cost of adjusting investment goods production
Fiscal Authority		
$\frac{\overline{G}}{Y}$	0.2	Steady state proportion of government expenditures
$\frac{bG}{Y}$	0.41	Steady state proportion of government debt
Central Bank		
ρ_r	0.8	Smoothing parameter of Taylor rule
ϕ_π	1.5	Inflation gap coefficient of Taylor rule
ϕ_y	0.25	Output gap coefficient of Taylor rule
ρ_b	0.8	Smoothing parameter of exogenous debt policy

Table 2: Comparison of Welfare Costs under alternative monetary policy regimes (Measured in percentage points of steady state consumption stream)

Credit Shock

Monetary Policy	Welfare Cost (ξ)
Term-Premium Pegging	2.0
Taylor Rule	1.82

Productivity Shock

Monetary Policy	Welfare Cost (ξ)
Term-Premium Pegging	-3.86
Taylor Rule	-3.51

Table 3: Comparison of Welfare Costs ($\Gamma = 0.15$) under alternative monetary policy regimes (Measured in percentage points of steady state consumption stream)

Credit Shock

Monetary Policy	Welfare Cost (ξ)
Term-Premium Pegging	1.27
Taylor Rule	1.13

Productivity Shock

Monetary Policy	Welfare Cost (ξ)
Term-Premium Pegging	-5.55
Taylor Rule	-5.37

Appendix

A. Perpetual or Long-Term Bonds

We use the identical definition of long-term bonds as in section 2.1 of Sims and Wu (2020). However, for the sake of completeness, we reiterate the main features here.

Both wholesale firm and government issue perpetual bonds to finance their investment and consumption expenditure, respectively. The coupon payment on these bonds decay at a constant rate of $\kappa \in [0, 1]$, such that a bond issued at t pays its holder dollar one at $t+1$, κ dollars at $t+2$, κ^2 at $t+3$ and so on. Let $B_{j,t-1}$ denote the total coupon liability of entity j in period t due to the bonds issued till period $t-1$. Also, let $NB_{j,t}$ denote the new bonds issued at t so that the following holds:

$$B_{j,t-1} = NB_{j,t-1} \cdot 1 + NB_{j,t-2} \cdot \kappa + NB_{j,t-3} \cdot \kappa^2 + ... \tag{A.1}$$

Using the above equation, we get the following identity:

$$NB_{j,t} = B_{j,t} - \kappa B_{j,t-1}$$

It is useful to note that one does not need to track the new issues at each date. Rather, those can be inferred using the total coupon liability.

Let the bonds issued at t be priced in the market at Q_t. It means that the present value of its associated stream of future coupon payments is priced as follows:

$$Q_t \equiv 1 + \kappa + \kappa^2 + \kappa^3 + ... = \frac{1}{1-\kappa} \tag{A.2}$$

The stream of future ($t+1$ onwards) coupon payments associated with bonds issued at $t-j$ is given by

$$\kappa^j + \kappa^{j+1} + ... = \frac{\kappa^j}{1-\kappa}$$

Using equation (A.2), the present value of the above stream of payments (or bonds issued at $t-j$) is $\kappa^j Q_t$ at t. This means that it is enough to know the price of new bonds to know the value of all outstanding bonds issued by entity j which is given by,

$$Q_t{\cdot}NB_{j,t}{+}\kappa Q_t{\cdot}NB_{j,t-1}{+}\kappa^2 Q_t{\cdot}NB_{j,t-2}{+}... = Q_t(B_{j,t}{-}\kappa B_{j,t-1}){+}\kappa Q_t[NB_{j,t-1}{\cdot}1{+}NB_{j,t-2}{\cdot}\kappa{+}NB_{j,t-3}{\cdot}\kappa^2{+}...]$$

Using equation (A.1), the last term on RHS of above equation equals $B_{j,t-1}$. So, the value of outstanding bonds issued till date t equals $Q_t B_{j,t}$.

B. Production Firms

B.1 Retail firm

A unit continuum of monopolistically competitive retailers indexed by $f \in [0,1]$ purchases wholesale output and resells it at $P_t(f)$ to the final good firm. The perfectly competitive final good firm combines retailers output according to CES technology:

$$Y_t = \left(\int_0^1 Y_t(f)^{\frac{\epsilon_p - 1}{\epsilon_p}} df\right)^{\frac{\epsilon_p}{\epsilon_p - 1}} \tag{B.1.1}$$

where ϵ_p is the elasticity of substitution between different varieties produced by retailers. The demand function for retailer $f's$ output is standard:

$$Y_t(f) = \left(\frac{P_t(f)}{P_t}\right)^{-\epsilon_p} Y_t$$

Plugging it in equation (B.1.1) gives the final good price as an index of retailer prices:

$$P_t^{1-\epsilon_p} = \int_0^1 P_t(f)^{1-\epsilon_p} df \tag{B.1.2}$$

There exists nominal rigidites like Calvo (1983) such that retailers can reset their prices only with a probability of $1 - \phi_p$ each period. Each retailer who resets price at t will try to maximize the present discounted value of the real dividends keeping in mind the possibility that it could never get to reset the price again in future. Its Lagranian will then look like:

$$\mathbb{L}_t = \mathbb{E}_t \sum_{j=0}^{\infty} {\phi_p}^j \Lambda_{t,t+j} \left\{ P_t(f)^{1-\epsilon_p} {P_{t+j}}^{\epsilon_p - 1} Y_{t+j} - p_{w,t+j} P_t(f)^{-\epsilon_p} {P_{t+j}}^{\epsilon_p} Y_{t+j} \right\}$$

Setting its derivative with respect to $P_t(f)$ equal to zero results in the following:

$$\Pi_t^{\#} = \frac{P_t^{\#}}{P_t} = \frac{\epsilon_p}{\epsilon_p - 1}\frac{x_{1,t}}{x_{2,t}} \tag{B.1.3}$$

where $P_t^{\#}$ is the reset price at t which is equal for all retailers who get to reset their price at t, and $x_{1,t}$ and $x_{2,t}$ are auxiliary variables defined as:

$$x_{1,t} = p_{w,t}Y_t + \phi_p \mathbb{E}_t\left(\Lambda_{t,t+1}\Pi_{t+1}^{\epsilon_p}x_{1,t+1}\right) \tag{B.1.4}$$

$$x_{2,t} = Y_t + \phi_p \mathbb{E}_t\left(\Lambda_{t,t+1}\Pi_{t+1}^{\epsilon_p - 1}x_{2,t+1}\right) \tag{B.1.5}$$

The reset price in (B.1.3) is a constant mark-up $\left(\frac{\epsilon_p}{\epsilon_p-1}\right)$ over marginal cost which is given by $\frac{x_{1,t}}{x_{2,t}}$.

B.2 Capital Goods Firm

It converts the unconsumed (by household and government) output I_t into new capital $\hat{I}_t$. Its production function is given by:

$$\hat{I}_t = I_t\left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right]$$

where $S(.)$ denotes the investment adjustment cost function[6] similar to Christiano et al. (2005) that satisfies the following properties: $S(1) = S^{'}(1) = 0$ and $\kappa_I \equiv S^{''}(1) > 0$.

Its objective is to maximize the present discounted value of real profits at t given by:

$$\max_{I_t} \mathbb{E}_t \sum_{j=0}^{\infty} \Lambda_{t,t+1}\left\{p_{t+j}^k I_{t+j}\left[1 - S\left(\frac{I_{t+j}}{I_{t+j-1}}\right)\right] - I_{t+j}\right\}$$

The FOC is:

$$1 = p_t^k\left[1 - S\left(\frac{I_t}{I_{t-1}}\right) - S^{'}\left(\frac{I_t}{I_{t-1}}\right)\frac{I_t}{I_{t-1}}\right] + \mathbb{E}_t\left[\Lambda_{t,t+1}p_{t+1}^k\left(\frac{I_{t+1}}{I_t}\right)^2 S^{'}\left(\frac{I_{t+1}}{I_t}\right)\right]$$

[6]Specifically, it takes the following form: $S\left(\frac{I_t}{I_{t-1}}\right) = \frac{\kappa_I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2$

C. Steady State

We compute the steady state for a zero net inflation rate, which means $\Pi = 1$. Aggregate price index (B.1.2) can be rewritten as:

$$P_t^{1-\epsilon_p} = (1-\phi_p){P_t^{\#}}^{1-\epsilon_p} + \phi_p P_{t-1}^{1-\epsilon_p}$$

Using $\Pi_t^{\#} = \frac{P_t^{\#}}{P_t}$ and $\Pi_t = \frac{P_t}{P_{t-1}}$, we get

$$1 = (1-\phi_p){\Pi^{\#}}^{1-\epsilon_p} + \phi_p \Pi_t^{\epsilon_p - 1}$$

Therefore, steady-state $\Pi^{\#} = 1$. Since retailers simply repackage the wholesale firm's output, therefore

$$Y_{w,t} = \int_0^1 Y_t(f)df = Y_t \int_0^1 \left(\frac{P_t(f)}{P_t}\right)^{-\epsilon_p} df = Y_t \nu_t^p$$

where $\nu_t^p = \int_0^1 \left(\frac{P_t(f)}{P_t}\right)^{-\epsilon_p} df$ is a measure of price-dispersion in the retailer prices. Writing ν_t^p recursively, we get

$$\nu_t^p = (1-\phi_p)\Pi_t^{\#^{-\epsilon_p}} + \phi_p \Pi_t^{\epsilon_p} \nu_{t-1}^p$$

$\Pi = \Pi^{\#} = 1$ implies $\nu^p = 1$ and thus $Y_w = Y$. Investment does not change in steady state, so $\hat{I} = I$. Similarly, consumption doesn't change so $\Lambda = \beta$. From equation (3), we have $R^d = \frac{1}{\beta} = R^{re}$. We normalize total labor and capital cost as $p^k = L = L_d = 1$. Choose steady state utilization to be 1 so that utilization adjustment cost is δ_0.

We solve the DSGE model at a quarterly frequency. In order to target a steady state annual spread of $sp_B = 100$ basis points on government bonds, we set $R^B = (1+sp_B)^{\frac{1}{4}} * R^d$. It gives $Q_B = (R^B - \kappa)^{-1}$ and choosing $\Gamma = 0.27$ gives $\gamma = \Gamma/(1-\Gamma)$.

Using (B.1.3), steady state marginal cost is

$$MC = \frac{\epsilon_p - 1}{\epsilon_p}$$

Further steady state calculation is not possible without knowing the return on private bonds i.e. R^F. So, we solve for R^F using the following non-linear equations between (C.1)-(C.2):

$$Q = (R^F - \kappa)^{-1} \tag{C.1}$$

Using (20),

$$M_2 = \frac{\Lambda}{Q(1-\kappa\Lambda)}$$

which gives $M_1 = (M_2 - 1)\psi + 1$. Then, using (19), we get steady-state capital

$$K = \left(\frac{\alpha MC}{\frac{M_1}{\Lambda} - (1-\delta_0)M_1} \right)^{\frac{1}{1-\alpha}}$$

This means wholesale output is $Y_w = K^\alpha$. So, total output is $Y = Y_w$. Let the steady-state balance sheet of central bank be a fraction $fracb = 0.24$ of steady state output, i.e. $b_{cb} = Y * fracb/Q_B$. Also, let government borrowing be fraction $bgy = 0.41 * 4$, i.e., $bG = bgy * Y/Q_B$. This gives $b = bG - b_{cb}$. From (14), $\hat{I} = \delta_0 K$ and from (15) $f_w = \frac{\psi \hat{I}}{Q(1-\kappa)}$. Market clearing implies $f = f_w$. Lastly, binding regulatory constraint means

$$Qf\gamma = Q_B b \tag{C.2}$$

Using (16), steady state wage paid by wholesale firm is $w = MC(1-\alpha)K^\alpha$. Let government expenditure be fraction $gy = 0.2$ of total output, then $G = gy*Y$ and $C = Y - I - G$. Using (1),

$$\mu = \frac{1-\beta h}{C(1-h)}$$

and using (2),

$$\chi = \mu w$$

We know M_2, so $\nu_2 = M_2 - 1$ and from (18), we get $\nu_1 = 1 + \psi\nu_2$. Since $\delta'(1) = \delta_1$, therefore using (17), we have

$$\delta_1 = \frac{\alpha MC K^{\alpha-1}}{M_1}$$

Using (B.1.4) and (B.1.5), we get

$$x_1 = \frac{MC * Y}{1 - \phi_p \Lambda}$$

$$x_2 = \frac{Y}{1 - \phi_p \Lambda}$$

Steady state reserves are given by $re = Q_B b$. Let steady-state leverage of intermediaries be $levs = 4$, then net worth is $n = \frac{Qf + Q_B b + re}{levs}$. Deposits are $d = Qf + Q_B b + re - n$, modified leverage ratio is $\phi = \frac{Qf + \Delta Q_B b}{n}$, and from (23), $X = n - \sigma(Qf[R^F - R^D + \gamma(R^B - R^D)] + R^D n)$. Net revenue of CB is $T_{cb} = (R^B - R^{re}) Q_B b_{cb}$. And, lump-sum tax paid by households using (21) is $T = G + bG - T_{cb} - Q_B(bG - \kappa bG)$.

Let $A = Qf[R^F - R^D + \gamma(R^B - R^D)] + R^D n$, then

$$\theta = \frac{\Lambda(1 - \sigma)A}{Qf(1 + \Delta\gamma) - A\Lambda\sigma\phi}$$

Now, let $B = (A - R^D n)/Qf$, then $\tilde{\lambda} = \frac{nB\theta\phi}{A(1+\Delta\gamma)}$ and $\tilde{\lambda} = \frac{\lambda}{1+\lambda}\theta$ so we know λ. Similarly, $\tilde{\zeta} = (1/\gamma) * [(\theta\phi n(R^F - R^D)/A) - \tilde{\lambda}]$ and $\tilde{\zeta} = \frac{\zeta}{1+\lambda}$, so we know ζ.

The steady-state value of linearity coefficient a_t in $V_{it} = a_t n_{it}$ is given by (using binding leverage constraint)

$$a = \theta\phi \Rightarrow \Omega = 1 - \sigma + \sigma a$$