HONG KONG INSTITUTE FOR MONETARY AND FINANCIAL RESEARCH

OPTIMAL CREDIT, MONETARY, AND FISCAL POLICY UNDER OCCASIONAL FINANCIAL FRICTIONS AND THE ZERO LOWER BOUND

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HKIMR Working Paper No.13/2020

September 2020

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Abstract

I study optimal credit, monetary, and fiscal policy under commitment in a model where financial intermediaries face an occasionally binding financial constraint; the monetary authority faces a zero lower bound (ZLB); and the fiscal authority faces a budget constraint. Despite being inactive in the deterministic steady state, the credit policy is permanent in the risky steady state. Financial and productivity shocks can generate a tradeoff between inflation stability and financial stability, which is resolved in favour of the latter with the credit spread being virtually equal to zero under a reasonable calibration. As the ZLB prevents full-scale monetary easing when financial distress weighs on aggregate demand, monetary policy should be relatively tighter in normal times for a precautionary reason. Moreover, the optimal nominal interest rate is a bell-shaped function of productivity around the stochastic steady state, although it is sensitive to how much the central bank is constrained by its past commitments. Notwithstanding the mentioned policy tradeoff, the optimal Taylor type rule is strictly inflation targeting. However, the rule-based policy features too aggressive a credit intervention but insufficient monetary easing.

JEL classification: E44, E52, E6, C61

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* I would like to thank participants at several seminars and conferences for helpful comments. Especially, I am grateful to Tom Holden for his help with the dynareOBC toolkit and to journal editors and anonymous referees for their insightful suggestions. I declare that I have no relevant or material financial interests that relate to the research described in this paper. The views expressed in this paper are mine and do not represent the views of the Hong Kong Monetary Authority.

I. Introduction

New developments after the 2007-2009 global financial crisis (GFC) induces central banks to rethink their monetary policy framework. For example, neutral interest rates have been falling globally for years and this trend is expected to persist (Holston, Laubach and Williams, 2017). Thus, monetary policy is more likely to hit the zero lower bound (ZLB). In addition, financial shocks that disrupt financial intermediation (Ivashina and Scharfstein, 2010) and possibly the transmission mechanism of monetary policy (Altavilla, Canova and Ciccarelli, 2016) have received much attention. Indeed, Schularick and Taylor (2012) conclude that the financial system does not only amplify macroeconomic shocks but is also an independent source of volatility. Jermann and Quadrini (2012) find financial shocks to be an important driver of business cycles. To ease financial crunches, unconventional monetary policies such as quantitative easing (QE) have been made popular with the hope of reducing long-term interest rates, boosting lending, and stimulating real activity.[1] In this course, there are ongoing debates on how the current policy framework should evolve and if the policy toolkit should be expanded.

This paper tries to shed some new light on this topic from a specific angle. I study optimal credit, monetary, and fiscal policy under commitment (Ramsey policy) in a low-interest-rate environment with financial and macroeconomic disturbances. Credit policy is modelled as private asset purchases; monetary policy controls the nominal interest rate subject to the ZLB; and fiscal policy sets a labour tax subject to the government budget constraint. Despite a large literature on each of these policies (summarised in the next section), the normative aspect of the joint policy has not yet been fully understood. For example, credit policy may restore the functioning of financial markets on which the transmission mechanism of monetary policy depends. But the literature often only considers credit policy in a liquidity trap or, when credit policy is not available, debates whether monetary policy should respond to financial conditions (Curdia and Woodford, 2010). On the fiscal side, many countries are left with high levels of public debt after the GFC (see e.g. Oh and Reis, 2012; Caruso, Reichlin and Ricco, 2018), which must be stabilised by either inflation or fiscal surpluses going forward. In this context, potential losses on the central bank's balance sheet can increase the fiscal burden and make it more difficult to raise interest rates when the time comes (Evans et al., 2016).

In studying these issues, I focus on the Ramsey policy because the ability to commit has become more relevant in recent years, thanks to improved communication and active forward guidance. Moreover, expectation management has been at the centre of policy revisions[2] because, e.g., a flattened Phillips curve downplays the role of aggregate demand and emphasises the role of inflation expectations in controlling inflation. Svensson (2019) argues that central banks can adopt a "forecast targeting" strategy. Forecast targeting means that policy instruments are set such that the resulting forecasts of target variables, e.g. inflation, are desirable. Then, forward guidance is the default when central banks publish the paths of policy instruments and the forecasts of target variables that justify the policy decision.

In this paper, I employ a simple New Keynesian model augmented with Gertler and Kiyotaki (2010) style financial frictions. Financial intermediaries (referred to as banks) face a financial constraint derived from an agency problem between banks and depositors. A key feature of this

[1] It is relatively well established that unconventional monetary policy reduces the long-term interest rates. See, among many others, Gagnon et al. (2011) and Krishnamurthy and Vissing-Jorgensen (2011) for the Federal Reserve's QE, and Joyce et al. (2011) and Christensen and Rudebusch (2012) for the Bank of England's QE. However, unconventional monetary policy may have insignificant or unintended real effects through a bank lending channel, as shown by Chakraborty, Goldstein and MacKinlay (2017) and Acharya et al. (2017). Overall, it is widely believed that this kind of policy played a key role during the GFC, see Del Negro et al. (2017), Quint and Rabanal (2017), Cahn, Matheron and Sahuc (2017), etc.

[2] For example, Bernanke (2017)'s temporary price level targeting, Svensson (2019)'s average inflation targeting, and Reifschneider and Williams (2000)'s risk management rule all are techniques to exploit expectations and have received much attention from central banks.

model is that the financial constraint depends on banks' future profitability, which can be affected by the entire paths of policy instruments. The constraint is slack in normal times but binds endogenously in periods of financial distress, which can be triggered by a "Minsky moment". That is, agents in the economy suddenly realise that the leverage is too high. Such moments are captured by a financial shock that directly tightens the financial constraint.[3] When the constraint is binding, banks have difficulties rolling over their short-term debt, which leads to a collapse in asset prices and investment. The consequent deleveraging process continues to weigh on aggregate demand and inflation. Since the root of the problem is a disruption to financial intermediation, credit policy is designed to replace constrained intermediaries (banks) by an unconstrained intermediary (the government). Moreover, monetary policy can relax the financial constraint by lowering banks' real borrowing costs. Put differently, the lack of monetary easing due to the ZLB tightens the financial constraint. The ensuing widening of credit spreads limits the benefits of monetary easing at the ZLB (e.g. through a commitment of future interest rates). The tax policy is helpful because it gives the government an extra margin to affect inflation. However, the government cannot fully stabilise inflation and credit spreads simultaneously even with all three policies. Thus, our model features a tradeoff between inflation stability and financial stability.

My main findings are as follows. Relative to a laissez-faire equilibrium, the Ramsey equilibrium features a stochastic steady state with higher output and a credit spread that is virtually equal to zero. The government's incentive to narrow the credit spread depends primarily on the labour market efficiency in the steady state. To be specific, the optimal credit spread approaches zero quickly as the steady state labour taxes increase. Quantitatively, any realistic labour tax rate ($\geq 15\%$) would imply a zero credit spread. Knowing that the government will always bail out the markets ex post, banks are encouraged to choose a higher leverage level ex ante. As a result, the financial constraint is more often binding in the Ramsey equilibrium. This, in turn, requires the central bank to hold a positive amount of private assets and set a lower nominal interest rate on average. However, when the ZLB is slack, the risk that both the financial constraint and the ZLB can bind together gives the central bank a precautionary incentive to keep the nominal interest rate relatively higher. In the absence of a government spending shock, I do not find that the government budget to be an important constraint on optimal policy.

Next, I try to understand how optimal policy responds to different shocks. A contractionary financial shock has a much larger effect on output than on inflation. Thus, monetary policy following a traditional Taylor type rule is relatively unresponsive. The optimal monetary policy is more dovish by focusing on financial distress while inflation is allowed to rise modestly. A labour tax rebate helps curb inflation. If the economy falls into a liquidity trap, the central bank ramps up its asset purchase programme. Our model also contains a TFP shock. An unexpected improvement in productivity should relax the financial constraint thanks to a higher rate of return on bank assets. However, it could be particularly dangerous when a poor policy drives the economy into the liquidity trap in such a way that the shortfall in demand widens suddenly and the financial constraint is binding. To escape from the spiral of Fisherian deflation, the key is to lower the real interest rate, which is needed to stimulate aggregate demand and relax the financial constraint. In other words, there is no tradeoff between inflation stability and financial stability in this case. However, the tradeoff is prominent under a negative TFP shock. On one hand, inflation stability requires a tightening of monetary policy. On the other hand, stable inflation induces a binding financial constraint, which calls for monetary easing. Fortunately, the government is equipped with the credit policy to ease the financial strain and the tax policy to mitigate inflation. The tradeoff is found to be resolved in favour of monetary easing, regardless of the availability of the tax policy.

[3] Bordalo, Gennaioli and Shleifer (2018) and more generally the literature of behavioural finance provide the micro-foundation. López-Salido, Stein and Zakrajšek (2017) discuss how Minsky moments are complementary to financial frictions in understanding the role of credit risks in macroeconomic dynamics. Similar financial shocks are also considered in e.g. Dedola and Lombardo (2012); Eggertsson and Krugman (2012); Del Negro et al. (2017); Perri and Quadrini (2018).

In summary, the optimal nominal interest rate is a bell-shaped function of productivity around the stochastic steady state, i.e. monetary easing in response to both positive and negative TFP shocks. While monetary easing under high productivity is consistent with conventional wisdom, it is driven by the central bank's past commitments. When the central bank is less constrained by its past commitments, the nominal interest rate is mostly an increasing function of productivity.

Can the optimal policy be implemented by a familiar set of simple rules? I focus on the rules that let monetary policy respond to inflation and output, let credit policy respond to credit spread, and let the labour tax rate fixed. A more comprehensive study of optimal rules is left to future research. The optimised monetary rule echoes several findings in the literature, including a strong response to inflation but a muted response to output. Moreover, the inertia parameter exceeds but is close to 1, thus suggesting that the optimal monetary policy is forward looking and close to price level targeting. The optimised credit rule is found to be modestly persistent, suggesting a slow unwinding of the central bank's balance sheet. The associated welfare losses are small but the tradeoff between inflation stability and financial stability is prominent. Relative to the Ramsey policy, the optimised rules feature too aggressive a credit intervention but insufficient monetary easing.

II. Related literature

One of the main novelties of this paper is to jointly study two occasionally binding constraints (OBCs): the financial constraint and the ZLB. The emphasis on the former is in line with Del Negro, Hasegawa and Schorfheide (2016), Swarbrick, Holden and Levine (2017) and Jensen et al. (2020), who have shown that such nonlinearity helps capture the sudden and discrete nature of financial crises and eliminate the financial acceleration mechanism in normal times. While these papers treat the financial constraint in a perfect foresight manner, uncertainties surrounding the states of the constraint (binding or not) can have important implications. For example, Bocola (2016) finds that a liquidity facility like the ECB's LTRO is ineffective when banks deem that the likelihood of hitting the financial constraint is high. In this paper, this kind of behaviour is internalised by the Ramsey planner.

There is a large literature on monetary policy subject to the ZLB. A key lesson from this literature is that the nominal interest rate should be kept at zero for longer once it has hit the ZLB (Eggertsson and Woodford, 2003). Even when the nominal interest rate is positive, the presence of the ZLB calls for a more dovish monetary policy (Adam and Billi, 2006; Nakov, 2008) because the possibility of hitting the ZLB in the future reduces the output and inflation expectations today. In the early literature, the duration of the ZLB episode is largely exogenous, depending on a shock to the natural interest rate. Drawing on experience during the GFC, more recent work (Del Negro et al., 2017; Benigno, Eggertsson and Romei, 2020) models the origin of the ZLB episode by financial shocks that disrupt financial intermediation. This paper makes two contributions in this regard. First, I show that both positive and negative productivity shocks can drive the economy to the zero bound. Second, in contrast to the literature, the ZLB risks induce a relatively higher nominal interest rate in normal times.

This paper also belongs to the growing literature on normative unconventional (credit) policy. Particularly, I share Bianchi (2016)'s emphasis on the risk-taking channel of unconventional policy. The idea is that (financial) firms need to balance the desire to invest today with the risk of becoming financially constrained in the future. They have an incentive to borrow more, knowing that the more they borrow, the larger transfers they can receive from bailouts. The bailout policy faces the tradeoff between the ex-ante overborrowing and the ex-post benefit of a faster recovery from a credit crunch. While this literature primarily focuses on time-inconsistent policy, **?** studies optimal QE under discretion. He assumes a portfolio adjustment cost such that aggregate demand depends on both the short- and long-term interest rates. Hence, unlike in our model, QE works through a portfolio balance channel and is effective only when the ZLB is binding.

A number of papers study optimised simple rules for unconventional policy. Foerster (2015) proposes a credit spread targeting rule with inertia. Conditional on monetary policy following a traditional Taylor rule, he concludes that a slow unwinding of the central bank's balance sheet is welfare improving. This is also found to be true in this paper provided that the credit policy is not too persistent. More generally, the optimal unconventional policy depends on the assumed monetary policy. Carrillo et al. (2017) study the interaction between conventional and unconventional monetary policy in a Bernanke-Gertler financial accelerator model. They focus on the relevance of Tinbergen's rule by comparing a monetary policy rule responding to both inflation and credit spreads and a dual rule regime with a Taylor rule and a credit-spread-targeting financial rule. They find that the former responds too much to inflation and not enough to spreads, i.e. tight money and tight credit. In our model, the optimised rule is found to be too tight on money but too loose on credit.

Finally, this paper takes seriously the government budget constraint by excluding the government from access to lump-sum taxation. In most papers studying unconventional policy, it is assumed either explicitly or implicitly that the government budget constraint is not binding. The exceptions include Bianchi (2016) in which the government finances its bailout policy using a payroll tax and potentially a debt tax. However, Bianchi (2016) does not allow the government to borrow because this would allow the government to "lend" its borrowing capacity to financially constrained firms. Jiao (2019) considers an emerging economy relying on inflation and currency depreciation to finance unconventional policy. The focus of this paper is on advanced economies where the government finances its asset purchases by the optimal combination of distortionary taxes, seigniorage, and inflation. In this regard, this paper extends the optimal fiscal and monetary policy literature (e.g. Christiano and Kehoe, 1991; Schmitt-Grohé and Uribe, 2004*b*; Siu, 2004, among many others) with a credit dimension. In this literature, the policy tradeoff is between tax-smoothing and price stability, which is resolved in favour of price stability even with small degrees of price rigidity. This result is found to largely remain true in the presence of financial frictions.

The rest of the paper is organised as follows. In the next section I present the model and the optimal policy problems. The quantitative method is described in section IV, followed by the main results in section V. I examine the optimal simple rules in section VI. The last section concludes the paper.

III. Model

The model is based on a small version of Gertler and Karadi (2011) in which I abstract from a number of standard features that only matter quantitatively, e.g. working capital, variable capital utilisation and price indexation. Financial intermediaries channel funds to make a fixed investment, but their role in other important markets, e.g. mortgage, is abstracted. The economy is populated by households, intermediate good producers, capital producers, financial intermediaries (referred to as banks), and a government. Intermediate good producers acquire labour and capital to produce differentiated goods, and set prices optimally when receiving a Calvo (1983) signal. Fixed investment is financed by state-contingent securities, which can be held by banks and the government. Banks collect deposits from households subject to an agency problem. The government controls the nominal interest rate, purchases private securities, sets tax rates, and issues government bonds.

I depart from Gertler and Karadi (2011) in two important ways. First, I assume that the central bank sets the risk-free nominal interest rate, instead of the real rate. An important implication of this (more realistic) assumption is that monetary policy generating unanticipated inflation can affect the real borrowing cost of banks and the government. In this way, monetary policy interacts with credit and fiscal policy. Second, our model is a monetary economy with money demand and supply. Money demand encourages the central bank to stabilise the nominal interest rate rather than inflation, and money supply generates seigniorage incomes for the government.

A. Households

There is a unit-continuum of infinitely lived households. Households consume final goods c_t and supply labour l_t. They save in bank deposits D_t and fiat money M_t. Deposits are risk-free one-period nominal bonds carrying a gross rate of return R_t. Money facilitates consumption purchases. Households also own financial and non-financial firms.

Each household consists of workers and bankers who pool consumption risk perfectly. Workers are hired by intermediate good producers and bring wages to the household. Bankers manage a bank and transfer profits to the household. It is convenient to assume that households do not save in their own banks. A complete consumption insurance allows us to work with a consolidated representative household. The household chooses consumption, labour supply, and savings to maximise:

$$\mathbb{W}_t = \left[\frac{(c_t - hc_{t-1})^{1-\sigma}}{1-\sigma} - \chi\frac{l_t^{1+\varphi}}{1+\varphi}\right] + \mathbb{E}_t\beta\mathbb{W}_{t+1}, \tag{1}$$

where $\sigma > 0$ is the measure of relative risk aversion, h is the habit parameter, $\chi > 0$ is the disutility weight on labour, $\varphi > 0$ is the (inverse of) Frisch elasticity of labour supply, and $0 < \beta < 1$ is the subjective discount factor. The household faces a budget constraint

$$c_t\left[1 + s(v_t)\right] + \frac{M_t}{P_t} + \frac{D_t}{P_t} + \tau_t \leq w_t l_t\left(1 - \tau_{w,t}\right) + D_{t-1}\frac{R_{t-1}}{P_t} + \frac{M_{t-1}}{P_t} + \mathcal{F}_t,$$

where $s(v_t)$ is a proportional transaction cost of consumption purchases, P_t is the price of final goods, w_t is the real wage rate, $\tau_{w,t}$ is the labour tax rate, τ_t is lump-sum taxes, and $\mathcal{F}_t$ are the net real transfers from firms. The transaction cost has the function form as in Schmitt-Grohé and Uribe (2004*b*),

$$s(v_t) = \mathcal{A}v_t + \frac{\mathcal{B}}{v_t} - 2\sqrt{\mathcal{A}\mathcal{B}},$$

where $v_t = \frac{P_t c_t}{M_t}$ is consumption-based money velocity and $\mathcal{A}$ and $\mathcal{B}$ are parameters.

The first-order necessary conditions are:

$$(c_t - hc_{t-1})^{-\sigma} - \mathbb{E}_t\beta h\left(c_{t+1} - hc_t\right)^{-\sigma} = \lambda_t^h\left(1 + 2\mathcal{A}v_t - 2\sqrt{\mathcal{A}\mathcal{B}}\right)$$

$$\chi l_t^{\varphi}/\lambda_t^h = w_t\left(1 - \tau_{w,t}\right), \tag{2}$$

$$\mathbb{E}_t\left[\Xi_{t,t+1}r_{t+1}\right] = 1, \tag{3}$$

$$v_t^2 = \frac{\mathcal{B}}{\mathcal{A}} + \frac{R_t - 1}{\mathcal{A}R_t}, \tag{4}$$

where $\Xi_{t,t+1} \equiv \beta\frac{\lambda_{t+1}^h}{\lambda_t^h}$ is the stochastic discount factor and $r_{t+1} = \frac{R_t P_t}{P_{t+1}}$ is the real interest rate.

B. Non-financial firms

There are two types of non-financial firms: capital producers and intermediate good producers.

Intermediate good producers. — There is a continuum of intermediate good firms indexed by $m \in [0,1]$. They have access to a Cobb-Douglas technology $y_{m,t} = A_t \left(\xi_t k_{m,t-1}\right)^{\alpha} l_{m,t}^{1-\alpha}$ where $0 < \alpha < 1$ is the capital share, A_t is total factor productivity, and $k_{m,t}$ is the capital stock at the end of period t. Let δ be the depreciation rate and ξ_t the quality of capital. Firm m acquires additional capital $i_{m,t} = k_{m,t} - (1-\delta)\,\xi_t k_{m,t-1}$. To finance its fixed investment, the firm issues securities $s_{m,t}$. Each unit of securities is a state-contingent claim to the future returns of one unit of capital. Following Gertler and Karadi (2011), I assume $s_{m,t} = k_{m,t}$[4] and consequently capital and securities have the same real price q_t. The real rate of return of holding securities for one period is given by

$$r_{k,t+1} \equiv \frac{z_{t+1} + (1-\delta)\,\xi_{t+1} q_{t+1}}{q_t}, \tag{5}$$

where z_t is the dividend rate on capital.

Let mc_t denote the real marginal cost. Cost minimisation gives

$$w_t = (1-\alpha)\, A_t \left(\frac{\xi_t k_{m,t-1}}{l_{m,t}}\right)^{\alpha} mc_t, \tag{6}$$

$$z_t = \alpha A_t \left(\xi_t\right)^{\alpha} \left(\frac{k_{m,t-1}}{l_{m,t}}\right)^{\alpha-1} mc_t. \tag{7}$$

Firm m faces a downward sloping demand $y_{m,t} = \left(\frac{P_{m,t}}{P_t}\right)^{-\varepsilon_t} y_t$ derived from a final good aggregator $y_t = \left[\int_0^1 y_{m,t}^{\frac{\varepsilon_t - 1}{\varepsilon_t}}\, dm\right]^{\frac{\varepsilon_t}{\varepsilon_t - 1}}$, where $P_{m,t}$ is the price of intermediate good m and $\varepsilon_t > 0$ is the elasticity of substitution. With probability $1-\gamma$, firm m can optimise price $P_{m,t}^*$ subject to the demand function by solving

$$\max \mathbb{E}_t \sum_{j=0}^{\infty} \gamma^j \Xi_{t,t+j} \left[\frac{P_{m,t}^*}{P_{t+j}} - (1+\tau_{y,t+j})\, mc_{t+j}\right] y_{m,t+j},$$

where $\tau_{y,t}$ is a production tax. Focusing on a symmetric equilibrium, the first-order condition (FOC) is given by

$$\mathbb{E}_t \sum_{j=0}^{\infty} \gamma^j \Xi_{t,t+j} \left[(1-\varepsilon_t)\left(\frac{1}{\prod_{s=1}^{j} \Pi_{t+s}}\right)^{1-\varepsilon_t} p_t^* + \varepsilon_t \left(\frac{1}{\prod_{s=1}^{j} \Pi_{t+s}}\right)^{-\varepsilon_t} (1+\tau_{y,t+j})\, mc_{t+j}\right] y_{t+j} = 0, \tag{8}$$

[4]This implies that firms can not borrow directly from households by paying a negative dividend. Otherwise the banking sector becomes trivial. Similar assumptions have been made in e.g. Bianchi (2016) where the dividend payment is constrained from below.

where $\Pi_t = \frac{P_t}{P_{t-1}}$ is inflation and $p_t^* = p_{m,t}^* = \frac{P_{m,t}^*}{P_t}$ is the optimised real price of intermediate goods.

Capital producers. — Given the market price q_t, capital producers maximise their expected discounted profits:

$$\max_{\{i_{t+j}\}_{j=0}^{\infty}} \mathbb{E}_t \sum_{j=0}^{\infty} \Xi_{t,t+j} \left[q_{t+j} i_{t+j} - f\left(k_{t+j-1}, i_{t+j}\right) \right],$$

where the cost function is given by

$$f(\cdot) = i_t + \frac{\eta}{2} \left(\frac{i_t}{\delta k_{t-1}} - 1 \right)^2 \delta k_{t-1},$$

and $\eta \geq 0$.[5] The first-order condition pins down the market price of new capital (Tobin's q)

$$q_t = 1 + \eta \left(\frac{i_t}{\delta k_{t-1}} - 1 \right). \tag{9}$$

C. Banks

Banks are financial intermediaries engaging in maturity and liquidity transformation. Bank i receives deposits amounting to $D_{i,t}$ from households and purchases $s_{i,t}$ units of securities from intermediate good producers. The balance sheet of bank i is

$$q_t s_{i,t} = \frac{D_{i,t}}{P_t} + n_{i,t},$$

where $n_{i,t}$ is the bank's real net worth at the beginning of period t. $n_{i,t}$ evolves according to

$$\begin{aligned} n_{i,t} &= q_{t-1} s_{i,t-1} r_{k,t} - D_{i,t-1} \frac{R_{t-1}}{P_t} \\ &= q_{t-1} s_{i,t-1} \left(r_{k,t} - r_t \right) + n_{i,t-1} r_t, \end{aligned}$$

where in the second line I use the balance sheet equation to substitute for $\frac{D_{i,t}}{P_t}$. Bank i's leverage is defined as

$$\phi_{i,t} = \frac{q_t s_{i,t}}{n_{i,t}}.$$

As in Gertler and Karadi (2011), banks shut down with probability r_n at the end of each period, upon which banks distribute their net worth to households. The notation r_n follows the idea that the probability of shutting down can be interpreted as an exogenous dividend rate. Then, bankers become workers. In the meantime, a similar number of workers from the same household randomly become new bankers. New bankers receive "start-up" funds from their household as a proportion ϖ of the total value of capital in the economy.[6]

Bank i chooses an investment plan $(s_{i,t})$ to maximize its expected present value of net worth

[5] Another popular specification of the cost function is $f(\cdot) = i_t + \frac{\eta}{2} \left(\frac{i_t}{i_{t-1}} - 1 \right)^2 i_t$, which renders a more complicated FOC. However, the results under both specifications are quantitatively similar.

[6] In Gertler and Karadi (2011), the start-up funds are proportional to the assets held by incumbent banks. I make this minor change to ensure that start-up funds are not affected by the central bank's asset purchasing.

upon closure

$$\begin{aligned} V_t(n_{i,t}) &= \max \mathbb{E}_t \sum_{j=0}^{\infty} r_n (1-r_n)^j \, \Xi_{t,t+j+1} n_{i,t+1+j} \\ &= \max \mathbb{E}_t \Xi_{t,t+1} \left[r_n n_{i,t+1} + (1-r_n) V_{t+1}(n_{i,t+1}) \right] \\ &= \nu_{n,t} n_{i,t}, \end{aligned}$$

where the third equality follows a conjecture that the value function is linear in net worth and the unknown time-varying coefficient $\nu_{n,t}$ is independent of i. The bank faces the financial constraint

$$\nu_{n,t} n_{i,t} - \theta_t q_t s_{i,t} \geq 0,$$

where $\theta_t \in [0,1]$ is an exogenous process controlling the tightness of the constraint and shocks to θ_t are referred to as financial shocks capturing "Minsky moments" in a reduced form (e.g. disturbances to haircut changing the effective value of net worth). The financial constraint can be expressed as an upper bound on leverage,

$$fc_{i,t} \equiv \frac{\nu_{n,t}}{\theta_t} - \phi_{i,t} \geq 0, \tag{10}$$

where $fc_{i,t}$ measures how far the bank is from hitting the financial bound. The financial constraint is derived from an agency problem as follows. Banks are able to declare bankruptcy and exit from the market. Should this happen, bankers would divert a proportion θ_t of the total assets to their family. Creditors can only reclaim the remaining funds. Therefore, creditors are willing to lend to a bank only if banks have no incentive to default, i.e. (10) not being violated.

Let the multiplier associated with (10) be $\lambda_t \geq 0$. The necessary conditions of the bank's problem include the complementary slackness condition

$$fc_{i,t} \lambda_t = 0, \tag{11}$$

and the first-order condition

$$\begin{aligned} \mathbb{E}_t \Xi_{t,t+1} \left(r_n + (1-r_n) \nu_{n,t+1} \right) \left(r_{k,t+1} - r_{t+1} \right) &\equiv \nu_{s,t} \\ &= \tfrac{\lambda_t}{1+\lambda_t} \theta_t \geq 0, \end{aligned} \tag{12}$$

which confirms λ_t independent of i. The unknown coefficient $\nu_{n,t}$ can be solved using (10) and (12):

$$\nu_{n,t} = \nu_t \left(\frac{\nu_{s,t}}{\theta_t - \nu_{s,t}} + 1 \right), \tag{13}$$

where $\nu_t \equiv \mathbb{E}_t \Xi_{t,t+1} \left(r_n + (1-r_n) \nu_{n,t+1} \right) r_t$. (13) verifies the earlier conjecture. It follows that heterogeneity in banks' net worth and asset holdings does not affect aggregate dynamics.

If the financial constraint never binds, $\nu_{n,t} = \nu_t = 1$ collapses to the standard Euler equations. $\nu_{s,t} = 0$ indicates complete monetary policy transmission from the short-term rate r_t to the long-term rate $r_{k,t}$. In general, (12) suggests that there are rich dynamics in the spread between the long-term interest rate $r_{k,t}$ and the short-term interest rate r_t. Following Bocola (2016), the credit spread $\mathbb{E}_t\left(r_{k,t+1} - r_{t+1}\right)$ can be decomposed into a liquidity premium and a risk premium:

$$\begin{aligned}\mathbb{E}_t\left(r_{k,t+1} - r_{t+1}\right) &= \underbrace{\frac{\frac{\lambda_t}{1+\lambda_t}\theta_t}{\mathbb{E}_t\Xi_{t,t+1}\left(r_n + \left(1-r_n\right)\nu_{n,t+1}\right)}}_{\text{Liquidity premium}} \\ &+ \underbrace{COV_t\left[\frac{-\Xi_{t,t+1}\left(r_n + \left(1-r_n\right)\nu_{n,t+1}\right)}{\mathbb{E}_t\Xi_{t,t+1}\left(r_n + \left(1-r_n\right)\nu_{n,t+1}\right)}, \left(r_{k,t+1} - r_{t+1}\right)\right]}_{\text{Risk premium}}.\end{aligned} \tag{14}$$

When the financial constraint is binding, the liquidity premium is positive ($\frac{\lambda_t}{1+\lambda_t}\theta_t > 0$), reflecting banks' inability to raise external funds. Because the current period net worth $n_{i,t}$ is exogenous to individual banks, hitting the financial bound forces banks to sell their assets. As long as $\eta > 0$ in (9), the fire sale weighs on asset prices and hence impairs the net worth, a consequence that banks do not internalise. This completes a vicious loop, which is known as the financial acceleration mechanism. In this case, $\nu_{n,t} > \nu_t$ means that net worth is more valuable than deposits because the former helps relax the financial constraint. $\nu_{s,t} > 0$ represents incomplete monetary policy transmission.

The possibility of hitting the bound in the future implies that banks demand a premium to hold risky assets. The size of the premium does, in general, depend on all three policies. Suppose that there is no credit nor fiscal policy. Monetary policy is inflation targeting and restricted by the ZLB. Under financial distress, $\nu_{n,t}$ tends to increase and $r_{k,t+1}$ tends to fall. Meanwhile, the adjustment of r_{t+1} is limited by the nominal rigidity and the ZLB. Consequently, the risk premium is positive. It follows that a successful policy should reduce the risk premium by expectation management. Indeed, Bocola (2016) shows that credit policy tends to be more effective in states with a low risk premium. However, expectations about the future financial constraint only matter to policymakers when the constraint is already binding today. To see this point, note that the policy target is to minimise $\nu_{s,t}$ instead of the credit spread. Combing (14) with (13) shows that $\nu_{s,t}$ equals zero irrespective of future risks as long as the financial constraint is slack and is forward looking otherwise:

$$\begin{aligned}\nu_{s,t} &= \mathbb{E}_t\Xi_{t,t+1}\left(r_n + \left(1-r_n\right)\nu_{t+1}\left(\frac{\nu_{s,t+1}}{\theta_t - \nu_{s,t+1}} + 1\right)\right)\mathbb{E}_t\left(r_{k,t+1} - r_{t+1}\right) \\ &+ COV_t\left[\Xi_{t,t+1}\left(r_n + \left(1-r_n\right)\nu_{t+1}\left(\frac{\nu_{s,t+1}}{\theta_t - \nu_{s,t+1}} + 1\right)\right), \left(r_{k,t+1} - r_{t+1}\right)\right].\end{aligned}$$

D. The government

Following the standard approach in the public finance literature, the specific agency that implements each policy is abstracted from the model. By focusing on a consolidated government, it is implicitly assumed that the central bank can receive fiscal support for its balance sheet, which could be particularly necessary when the balance sheet is large (Del Negro and Sims, 2015; Benigno and Nisticò, 2020). The government holds a proportion $\mathcal{P}_t \in [0, 1]$ of the total securities issued by intermediate good producers,[7] which renders a quadratic resource cost

$$\tau_{\mathcal{P}}\left(\mathcal{P}_t q_t s_t\right)^2,$$

[7] In an early version of this paper, I compare the three credit measures laid out by Gertler and Kiyotaki (2010), namely asset purchases, liquidity facilities, and equity injections. It can be shown that without any further distortions introduced in the model, these measures only differ in a trivial way. I focus on an asset purchase programme in this paper because it is the easiest to understand.

where $\tau_{\mathcal{P}} \geq 0$ is a parameter. Following the literature (Gertler and Karadi, 2011; Dedola, Karadi and Lombardo, 2013; Foerster, 2015), this cost represents inefficient public activities in private financial markets or the cost of strengthened financial surveillance.[8] Because of this cost, the government's asset purchases may increase the fiscal burden even when the credit spread is positive.

The consolidated budget constraint is given by

$$\begin{aligned} g_t + \tfrac{R_{t-1}}{\Pi_t} b_{t-1} + \tfrac{m_{t-1}}{\Pi_t} + \mathcal{P}_t q_t s_t + \tau_{\mathcal{P}} \left(\mathcal{P}_t q_t s_t\right)^2 = \\ \tau_t + w_t l_t \tau_{w,t} + \textstyle\int_0^1 \tau_{y,t} mc_t y_{m,t} dm + b_t + m_t + \mathcal{P}_{t-1} q_{t-1} s_{t-1} r_{k,t}, \end{aligned} \tag{15}$$

where tax revenues include labour taxes $w_t l_t \tau_{w,t}$, production taxes $\int_0^1 \tau_{y,t} mc_t y_{m,t} dm$, and lump-sum taxes τ_t; g_t is exogenous wasteful government consumption; $m_t = \frac{M_t}{P_t}$ are real money balances; and $b_t = \frac{B_t}{P_t}$ and B_t is a one-period state-noncontingent nominal asset. As in Gertler and Karadi (2011), B_t can be interpreted as either government bonds or reserves. In the former case, D_t denotes the sum of bank deposits and government bonds held by households. In the latter case, B_t is part of the bank assets. Assuming that the agency problem does not apply to reserves, B_t simply drops out of the bank's problem.

E. *Competitive equilibrium*

DEFINITION 1: *Given policies $\{\tau_{w,t}, \tau_{y,t}, R_t, \mathcal{P}_t, \tau_t\}$, exogenous processes $\{A_t, \xi_t, \theta_t, g_t, \varepsilon_t\}$, and initial conditions, a competitive equilibrium of aggregate dynamics is a set of plans*

$$\{c_t, l_t, m_t, P_t^*, \Pi_t, pd_t, y_t, mc_t, k_t, s_t, w_t, z_t, q_t, i_t, \nu_{n,t}, n_t, b_t\},$$

satisfying households' FOCs (2, 3, 4), the optimal pricing of intermediate goods (8), the law of motion of the price index

$$1 = (1-\gamma) p_t^{*1-\varepsilon_t} + \gamma \Pi_t^{\varepsilon_t - 1}, \tag{16}$$

the law of motion of price dispersion

$$pd_t = (1-\gamma) p_t^{*-\varepsilon_t} + \gamma \Pi_t^{\varepsilon_t} pd_{t-1}, \tag{17}$$

the production function

$$y_t pd_t = A_t \left(\xi_t k_{t-1}\right)^{\alpha} l_t^{1-\alpha}, \tag{18}$$

the law of motion of capital

$$k_t = i_t + (1-\delta) \xi_t k_{t-1}, \tag{19}$$

the cost minimisation conditions (6, 7) without subscript m, the FOC of capital producers (9), the FOC of banks

$$\nu_{s,t} \geq 0, \tag{20}$$

[8] Dedola, Karadi and Lombardo (2013) add a linear term in the cost function but they only find the coefficient on the quadratic term playing an important role.

the financial constraint

$$fc_t \equiv \frac{\nu_{n,t}}{\theta_t} - \phi_t \geq 0, \tag{21}$$

the complementary slackness condition

$$\nu_{s,t} fc_t = 0, \tag{22}$$

the solution of banks' value function (13), the law of motion of net worth

$$n_t = (1 - r_n)\left(q_{t-1}s_{t-1}\mathcal{P}_{t-1}\left(r_{k,t} - r_t\right) + n_{t-1}r_t\right) + \varpi q_{t-1}s_{t-1}, \tag{23}$$

the government budget constraint (15), and finally two market clearing conditions

$$y_t = c_t\left[1 + s\left(v_t\right)\right] + f\left(k_{t-1}, i_t\right) + \tau_{\mathcal{P}}\left(\mathcal{P}_t q_t s_t\right)^2 + g_t, \tag{24}$$

$$s_t = k_t, \tag{25}$$

where $pd_t \equiv \int_0^1 \left(\frac{P_{m,t}}{P_t}\right)^{-\varepsilon_t} dm$*;* λ_t^h*,* v_t*,* $r_{k,t}$*,* $\nu_{s,t}$*, and* ν_t *are defined in the text, leverage is defined as* $\phi_t = \frac{q_t s_t (1-\mathcal{P}_t)}{n_t}$.

F. Policy

The jointly optimal credit, monetary, and fiscal policy is a set of plans $\{\tau_{w,t}, \tau_{y,t}, R_t, \mathcal{P}_t, \tau_t\}$ that maximises (1) subject to the competitive equilibrium.[9] There are three sources of inefficiency in the model, namely the financial constraint, nominal rigidity, and imperfect competition.[10] I focus on the first two sources and assume throughout the paper that the inefficiency of imperfect competition is offset by a constant production subsidy $\tau_y = -\frac{1}{\bar{\varepsilon}}$.[11]

Formally, I consider the following Ramsey problem.

DEFINITION 2: *A debt Ramsey equilibrium solves* $\{\tau_{w,t}, R_t, \mathcal{P}_t\}$ *to maximise (1) subject to the competitive equilibrium and the ZLB,* $\ln R_t \geq 0$*. There is a production subsidy* $\tau_y = -\frac{1}{\bar{\varepsilon}}$ *financed by fixed lump-sum taxes. The net government deficit is financed by public debts.*

Since the first-order condition with respect to public debt features a unit root, the local approximation technique used to solve the model (to be discussed later) is inaccurate in long simulations, which are inevitable to compute most interesting statistics in our highly nonlinear model. Moreover, the accuracy can be particularly poor when we calculate welfare using a second-order approximation. Therefore, it is convenient to consider a stationary "lump-sum Ramsey equilibrium", in which the government budget is not a binding constraint.

DEFINITION 3: *A lump-sum Ramsey equilibrium solves* $\{\tau_{w,t}, R_t, \mathcal{P}_t\}$ *to maximise (1) subject to the competitive equilibrium and the ZLB,* $\ln R_t \geq 0$*. There is a production subsidy* $\tau_y = -\frac{1}{\bar{\varepsilon}}$*.*

[9] The problem can be somewhat simplified by noting that (20) is a redundant constraint at least locally around the chosen steady state. This can be confirmed in a quantitative analysis as the Lagrange multiplier associated with this constraint always equals zero. Intuitively, the government has no incentive to overinvest in physical capital.

[10] One may consider money demand motivated by a transaction cost and the costly capital production as extra sources of distortion

[11] This assumption is unlikely to change our main results. As shown by Schmitt-Grohe and Uribe (2004*a*), imperfect competition only shifts average optimal inflation upwards. This is because the social planner would like to tax money balances as an indirect way to tax monopoly profits.

Lump-sum taxes are set to balance the government budget period by period. The steady state of the economy is not chosen optimally but is equal to that of the debt Ramsey equilibrium.

In the lump-sum Ramsey equilibrium, the main difference between the chosen steady state and its optimal steady state concerns the labour tax rate, which is 30% in the former and -0.05% in the latter under my calibration. I focus on the high tax steady state for three reasons: 1) the average tax wedge across OECD countries is about 37% since 2000 according to OECD Tax Statistics; 2) to make the debt and lump-sum Ramsey equilibria more comparable; and 3) to capture labour market imperfections that are not explicitly modelled. In appendix A, I show that the lump-sum Ramsey equilibrium behaves similarly to the debt Ramsey equilibrium provided that they share the same steady state. Therefore, the lump-sum Ramsey model is employed as the workhorse model throughout the paper and is referred to as the Ramsey equilibrium/model for convenience. In solving the Ramsey equilibrium, I follow the "timeless" perspective advocated by Woodford (2003). First-order conditions are derived using Matlab's symbolic toolbox. Then, the equilibrium is represented by a system of difference equations, which can be solved numerically using the method discussed in the next section. To compare this with the Ramsey policy, I consider a laissez-faire equilibrium defined as follows:

DEFINITION 4: *A laissez-faire equilibrium is a competitive equilibrium where $\mathcal{P}_t = 0$, $\tau_{w,t} = \bar{\tau}_w$, and the monetary policy follows a conventional Taylor rule*

$$\log \frac{R_t}{\bar{R}} = \max\left\{0.8 \log \frac{R_{t-1}}{\bar{R}} + (1-0.8)\left(1.5 \log \frac{\Pi_t}{\bar{\Pi}} + 0.125 \log \frac{y_t}{\bar{y}}\right), -\log \bar{R}\right\},$$

$\bar{\tau}_w$, $\bar{\Pi}$, and $\bar{y}$ are the steady-state variables. Once more, lump-sum taxes are set to balance the government budget period by period, and the steady state of the economy equals that of the debt Ramsey equilibrium.

Now I briefly discuss policy tradeoffs and then move to quantitative exercises.

G. Policy tradeoffs

By purchasing private securities, the government acts as a financial intermediary. Since the government faces no financial constraint, credit policy effectively replaces inefficient financial intermediaries (banks) with an efficient one (the government). The policy pass-through is as follows. As discussed earlier, the binding financial constraint forces banks to sell their assets. This creates a decline in aggregate demand, lowering both output and inflation. Credit policy makes up the shortfall in asset demand, which improves asset prices and hence the bank net worth through a capital gain. Consequently, the financial constraint is relaxed and the credit spread narrows. However, the government may not absorb all assets sold off because of the recourse cost. At the margin, there could be a small yet positive credit spread. In this case, banks are crowded out from profitable investment and need more time to rebuild net worth.

When the output gap and inflation move in the same direction, monetary policy ought to be a powerful tool. However, as noted in Carrillo et al. (2017), monetary policy may not be able to simultaneously stabilise both the output gap and inflation in the presence of a financial accelerator mechanism. In addition to the standard Euler equation channel, monetary policy also affects the financial constraint up to its ability to adjust the real interest rate, see (23) and (21).[12] To minimize

[12] How monetary policy affects the financial constraint is a key determinant of its effectiveness. In Brunnermeier and Koby (2017), monetary easing relaxes the constraint until reaching a reversal rate, below which further easing tightens the constraint and reduces lending. In Cavallino and Sandri (2019), monetary easing tightens the constraint when the economy faces a premium on international financial markets. In this paper, I focus on the ZLB as a liquidity trap rather

the credit spread, the central bank may tolerate positive inflation at the margin. This trade-off between financial stability and inflation stability can be particularly significant if an inflationary shock tends to tighten the financial constraint, e.g. a negative TFP shock. Thus, it is helpful to have a tax policy that gives the government an extra margin to affect inflation. The distortionary labour tax can also be used to affect asset prices through the capital-labour ratio, i.e. an increase in labour supply must be matched by an increase in investment demand. Since movements in asset prices are key to the financial accelerator mechanism, this tax policy can be used to ease the financial strain.

If the government commits to addressing financial frictions, banks expect higher asset prices and lower borrowing costs under financial distress. Knowing that future financial crises will have a smaller impact on them, banks are willing to take a higher leverage in normal times, resulting in more fixed investment. This is the risk-taking channel that is relevant to all policies. However, the more deeply banks are leveraged, the more likely they are to hit the financial bound. Consequently, the government has to conduct costly interventions more often. In this way, the government faces a tradeoff in encouraging risk-taking behaviour (or discouraging precautionary behaviour). As noted by Bianchi (2016), the risk-taking channel makes optimal policy time-inconsistent. The government is tempted to announce a relatively small stimulation package ex ante, which is not optimal ex post.

IV. Quantitative method

Ideally the model should be solved by global methods. However, the Ramsey equilibrium contains too many state variables, some of which are multipliers associated with forward-looking constraints.[13] The model is therefore difficult to solve even using methods that are explicitly designed to deal with large state space, such as that of Maliar and Maliar (2015). Fast algorithms such as that of Guerrieri and Iacoviello (2015) based on piecewise linearisation gives, however, certainty equivalent results.

I employ the approach of Holden (2016), which can easily be implemented by Holden's "Dynare-OBC" toolkit.[14] The core algorithm is based on Holden (2019) which solves models that are linear apart from OBCs under perfect foresight. The idea of this algorithm is to hit the inequality-constrained variables with endogenous news (anticipated) shocks such that the inequality constraint is always satisfied. Solving the model amounts to finding the appropriate news shocks, which can be represented by a linear complementarity problem. The solution is virtually the same as the one computed by Guerrieri and Iacoviello (2015)'s algorithm. The main advantage of Holden (2016)'s generalised algorithm is to allow us capturing the role of risks. First, it can solve models that are nonlinear apart from OBCs by high-order approximations. Second, the risk of hitting OBCs can be taken into account in the spirit of Adjemian and Juillard (2013). For this purpose, it integrates the model over a certain period of future uncertainties to approximate rational expectations. To balance between accuracy and speed, I use 50 periods in practice.

Throughout the paper, I compute second-order approximations of the model under rational expectations (RE, with integrating over future uncertainties). Hence, I capture the precautionary

than the reversal bound of Brunnermeier and Koby (2017). Indeed, the reversal rate seems to be somewhere below the ZLB (or some small negative number if the lower bound is not zero). See, for example, a speech by Benoît Cœuréthe in 2016: https://www.ecb.europa.eu/press/key/date/2016/html/sp160728.en.html. Above the reversal rate, empirical work (e.g. Alessandri and Nelson, 2015) finds that monetary easing can strengthen the balance sheet condition of financial intermediation. In Brunnermeier and Sannikov (2016), this positive effect originates from capital gains. In our model and Carrillo et al. (2017), this positive effect is also captured by the ability of monetary policy to control the short-term real interest rate. The wider the credit spread, the larger is the effect of monetary easing on bank net worth. Naturally, monetary policy is more effective if it can affect the contemporary shortterm rate, i.e. under the assumption that the real interest rate is state-contingent in real terms (pre-determined in nominal terms).

[13] Bianchi (2016) solves the Ramsey policy in a model with occasionally binding financial constraints by policy function iteration. When there are not enough instruments to render constrained-efficient allocations, the system contains seven state variables in total, two of which are multipliers associated with forward-looking constraints.

[14] DynareOBC is available at https://github.com/tholden/dynareOBC.

effects stemming from both OBCs and second-order terms. To see how OBC related risks affect model behaviour, I also compute a "perfect-foresight (PF)" solution by assuming that economic agents ignore the possibility of hitting OBCs in the future and are always surprised when hitting OBCs.[15]

A. *Calibration*

TABLE 1—CALIBRATION

Description	Parameter	Value
Discount factor	β	0.9987
Relative risk aversion	σ	2
Habit	h	0.7
labour dis-utility weight	χ	48
Frisch elasticity (inverse)	φ	0.4
Parameter of consumption transaction cost	$\mathcal{A}$	0.0111
Parameter of consumption transaction cost	$\mathcal{B}$	0.07524
Calvo parameter	γ	0.779
Markup (steady state)	$\frac{\bar{\varepsilon}}{\bar{\varepsilon}-1}-1$	0.2
Capital share	α	0.33
Depreciation rate	δ	0.025
Elasticity of investment (inverse)	η	1.728
Survival probability of banks	$1-r_n$	0.972
Transfer rate from households to new banks	ϖ	$\frac{1-(1-r_n)/\beta}{4}$
Fraction of divertable assets (steady state)	$\bar{\theta}$	0.247
Government consumption-to-GDP ratio (steady state)	$\frac{\bar{g}}{\bar{y}}$	0.2
Government debt-to-GDP ratio (steady state)	$\frac{\bar{b}}{\bar{y}}$	0.7
Credit policy cost	$\tau_{\mathcal{P}}$	0.0005

Table 1 summarises parameter values where letters under a bar denote deterministic steady states. I use a relatively small discount factor to capture low neutral interest rates. $\beta = 0.9987$ implies a steady state real interest rate of 0.52%, matching the average yield on US 10-year treasury inflation-indexed securities since 2009. I choose $\chi = 48$ to match the steady-state working hours of about 40 hours per week, taking as given the labour tax rate. The inverse Frisch elasticity φ is set to 0.4 and the relative risk aversion is set to 2, both within typical ranges in the literature. The Calvo parameter γ and the inverse elasticity of investment η are borrowed from Gertler and Karadi (2011). The parameters of the consumption transaction cost are borrowed from Schmitt-Grohé and Uribe (2004*b*). The habit parameter h, the depreciation rate δ, the capital share α, the markup $\frac{\bar{\varepsilon}}{\bar{\varepsilon}-1}-1$, and the government consumption-to-GDP ratio $\frac{\bar{g}}{\bar{y}}$ are set to conventional values. The government debt-to-GDP ratio is set to 0.7, in line with relatively high levels of public debt in many advanced economies in recent years.[16] The parameter of the resource cost is set to 0.0005. As there is no hard evidence to quantify this cost, $\tau_{\mathcal{P}}$ is picked rather arbitrarily only to ensure that credit policy is not dominated by other policies. But our results are robust to reasonable variations in $\tau_{\mathcal{P}}$.

[15]I abuse the term slightly because the "PF" solution still captures precautionary effects stemming from secondorder terms. In practice, the PF solution is computed without integrating future uncertainties

[16]Note that B_t denotes government bonds held by the public, excluding those held by the central bank. The relevant ratio in the US is between 0.7-0.8 in recent years.

There are three parameters in the financial sector, namely r_n, $\bar{\theta}$, and ϖ. Following Gertler and Karadi (2011), I choose the survival rate $1 - \bar{r}_n$ that implies a decade of banks' average lifetime. I set the steady-state leverage ratio $\bar{\phi}$ to 4, which is considered as an average across sectors with vastly different financial structures.[17] Next, I choose a deterministic steady state where the financial constraint is slack.[18] This choice is supported by Bocola (2016)'s estimate in a similar model as the Lagrange multiplier associated with the financial constraint is close to zero on average. Our choices of η and r_n are also broadly consistent with Bocola (2016)'s estimates. The transfer rate to new banks is pinned down by the leverage ratio $\varpi = \frac{1-(1-r_n)/\beta}{\bar{\phi}}$. The steady-state proportion of divertable assets $\bar{\theta}$ is adjusted such that the financial constraint is close to its bound in the steady state ($\bar{\theta} = 0.247$). This is to ensure reasonable accuracy of approximation when the financial constraint is binding.

The behaviour of nonlinear models crucially depends on the specification of shocks. To avoid making the model too difficult to solve, I only consider two shocks: a TFP shock to drive business cycles (an impact on the supply side) and a financial shock to create Minsky moments (an impact on the demand side). The calibration goal is not to match statistical moments of a wide range of standard macroeconomic variables, but rather to generate enough uncertainty such that the precautionary effects are quantitatively reasonable. I assume both shocks following a log-AR(1) process. The TFP shock has an autocorrelation coefficient equal to 0.94 and the standard deviation of its innovations equal to 0.35%. The specification is identical to the post-1983 estimates of Smets and Wouters (2007) and fitting Solow residuals reasonably well (see e.g. Jermann and Quadrini, 2012). Next, the persistence of θ_t is 0.8, following Romer and Romer (2017)'s finding that financial distress itself is fairly persistent. To pin down the standard deviation of the financial shock, I solve the laissez-faire equilibrium, ignoring the ZLB, and match the standard deviation of annualized credit spreads (0.7%).[19] However, without features such as true default risk, I inevitably underestimate the average credit spread (2.07% in data and 0.18% in the model). Or I would overestimate the standard deviation if I matched the mean. Since the financial constraint is occasionally binding , the standard deviation appears to be a more natural choice for calibration.[20]

V. Quantitative results

A. *Simulations*

Table 2 reports key statistics of the Ramsey and laissez-faire equilibrium. Rows (a) and (d) present the ergodic mean and standard deviations under rational expectations. Rows (b) and (e) present the same ergodic statistics under perfect foresight. Rows (c1-c4) and (f1-f4) are risky steady states (RSSs) defined as in Coeurdacier, Rey and Winant (2011), which are obtained by simulating the economy under rational expectations with all realised shocks equal to zero until reaching a fixed point. RSSs are useful tools to illustrate how risk (i.e. unrealised shocks) affects the economy's behaviour.

[17]The literature has suggested alternative calibrations. For example, $\bar{r}_n$ can be set to match a dividend rate of 5.15% made by the 20 largest U.S. banks during 1965–2013 (Swarbrick, Holden and Levine, 2017). The steady-state leverage can be set to 16, the estimate of Quint and Rabanal (2017) in which the authors use GMM to estimate a similar model with the financial constraint always binding. These values change our results quantitatively but not qualitatively.

[18]It is well known that kinks of either the ZLB or borrowing constraints can introduce multiple equilibria. First, there are multiple deterministic steady states. I focus on a normal steady state with positive nominal interest rates and a silent credit policy. Second, there can be multiple paths reverting to a given steady state. Holden (2019)'s method allows us to test and select from these paths. Throughout the paper, should multiple paths emerge, I choose the one that escapes the bound as soon as possible.

[19]The data is Moody's seasoned Bbb corporate bond yield relative to the yield on 10-year treasury, 1983q1-20019q1. I ignore the ZLB here mainly because simulating the laissez-faire equilibrium with the ZLB is extremely slow.

[20]When the financial constraint is always binding, Gertler and Kiyotaki (2010) and Dedola, Karadi and Lombardo (2013) target the average spread of 1%

Table 2—Long run properties of the Ramsey and laissez-faire equilibrium

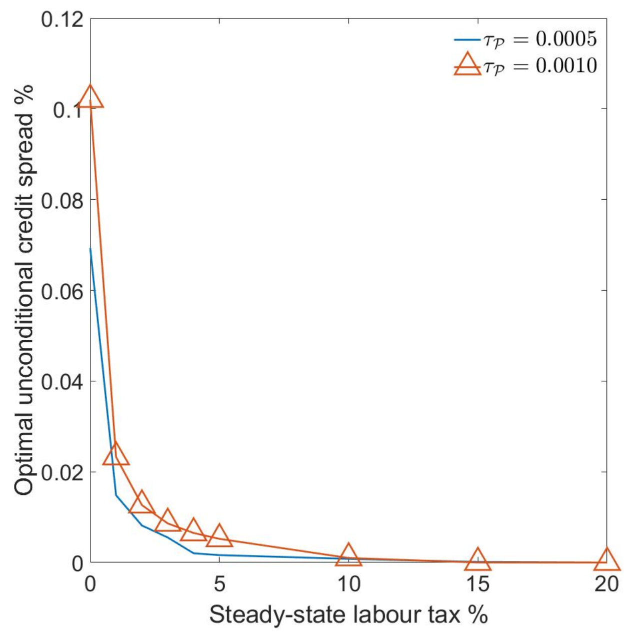
	$\log y_t$	$\log \Pi_t$	$\log R_t$	ZLB	Spread	ϕ_t	FC	$\mathcal{P}_t$	$\tau_{w,t}$
Laissez-faire									
(a) RE	-10.90	0.15	0.31	5.16	0.21	4.12	19.01	0.00	29.99
	(0.55)	(0.39)	(0.19)	-	(0.55)	(0.45)	-	(0.00)	(0.00)
(b) PF	-10.67	0.12	0.27	9.29	0.25	4.10	27.33	0.00	29.99
	(0.63)	(0.39)	(0.19)	-	(0.62)	(0.47)	-	(0.00)	(0.00)
(c1) RSS	-10.38	0.03	0.15	-	0.04	4.00	-	0.00	29.99
(c2) FC only	-9.96	0.03	0.13	-	0.00	3.96	-	0.00	29.99
(c3) ZLB only	-11.47	-0.34	0.29	-	0.00	6.38	-	0.00	29.99
(c4) No OBC	-9.83	0.00	0.10	-	0.00	4.00	-	0.00	29.99
Ramsey									
(d) RE	-9.70	0.02	0.12	11.81	0.00	4.00	51.29	0.95	29.92
	(0.51)	(0.02)	(0.11)	-	(0.00)	(0.08)	-	(0.99)	(0.41)
(e) PF	-9.81	0.00	0.07	31.41	0.00	3.89	15.58	0.12	29.96
	(0.53)	(0.01)	(0.08)	-	(0.00)	(0.11)	-	(0.39)	(0.25)
(f1) RSS	-9.64	0.02	0.14	-	0.00	4.02	-	1.85	29.91
(f2) FC only	-9.80	0.00	0.08	-	0.00	3.91	-	0.21	29.98
(f3) ZLB only	-9.81	0.00	0.09	-	0.00	3.98	-	0.00	29.99
(f4) No OBC	-9.82	0.00	0.10	-	0.00	3.99	-	0.00	29.99

Note: Rows labelled RE (PF) are ergodic statistics under rational expectations (perfect foresight), calculated using simulated series of 10 thousand periods. Numbers outside (inside) the parentheses are the mean (standard deviations). The column labelled ZLB (FC) is the frequency when the ZLB (financial constraint) is binding. Rows (c1-f4) and (f1-f4) are the risky steady states where economic agents take into account risks related to both, one, or none of the OBCs. The log transformed variables are multiplied by 100, ratios and rates are in percentage points, the leverage is in level.

First consider the laissez-faire equilibrium. Rows (a) and (b) show that precautionary effects stemming with OBCs induce the financial constraint less often binding in the RE model (19.01%) than in the PF model (27.33%). Since the financial constraint imposes an upper bound on leverage, the average level of average is lower in the PF model. On average, the precautionary effects reduces output by 0.23% but in the meantime improves economic stability (reducing volatility) and financial efficiency (narrowing the credit spread). The RE economy also experiences fewer ZLB episodes. This is because deleveraging under financial distress leads to low inflation, which prompts the central bank to cut the nominal interest rate. If hitting the ZLB, the central bank is less able to relax the financial constraint. The interactions between the two OBCs give private agents a precautionary motive to choose a higher rate of inflation, which can be seen in the RSSs by comparing row (c1) to row (c4). However, when the ZLB is the only OBC, there is downward pressure on inflation (comparing row c3 to row c4), which is the standard result in the literature.

In the Ramsey equilibrium, rows (d) and (e) show that optimal policy raises the average output by 1.2% or 0.86% relative to the laissez-faire policy, depending on how we calculate expectations. Moreover, the average nominal interest rate is lower, suggesting a more dovish monetary policy in general. Importantly, the optimal credit spread is virtually zero at all times. This result crucially depends on the labour tax rate in the steady state. As shown in figure 1, the optimal unconditional credit spread approaches zero quickly as the steady state labour tax increases, thereby suggesting that the optimal credit spread is zero in most countries where the labour tax rate is at least 10%. The zero credit spread remains even when credit policy, the policy designed specifically to address financial frictions, becomes more costly (see the red line marked with triangles). Intuitively, financial distress is increasingly painful when the labour market is more distorted because the markets of production factors, labour as well as capital are inefficient. Hence, the welfare gains of

FIGURE 1. OPTIMAL CREDIT SPREAD AND STEADY-STATE LABOUR TAX



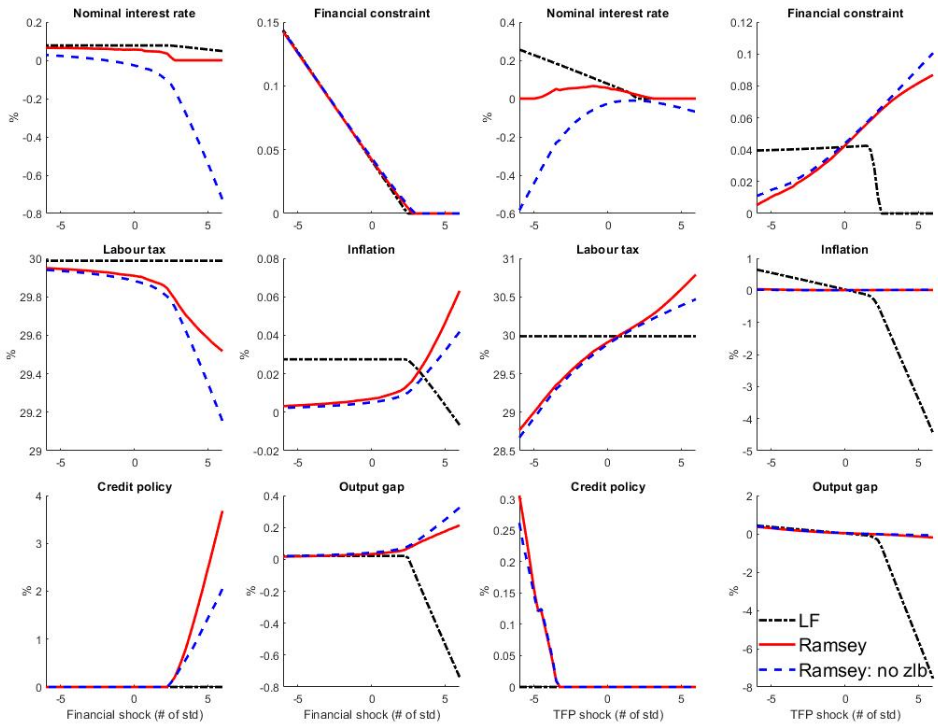
narrowing the credit spread dominate the associated cost. Given the expectation of a zero credit spread, banks have an incentive to take higher leverage. Therefore, relative to the PF model (row e), the RE model (row d) features higher output, leverage, and a more frequent binding financial constraint which, in turn, requires more asset purchases and tax rebates on average. Surprisingly, the average nominal interest rate is higher in the RE model. One possible explanation is that the Ramsey model simply hits the ZLB less often. But the causal relationship can be reversed.

I argue that the central bank intends to keep monetary policy relatively tight, which leads to fewer ZLB episodes. To illustrate this point, I resort to the RSSs shown in rows (f1)-(f4). If there is only one OBC, either the financial constraint or the ZLB, rows (f2)-(f3) show that the central bank loosens its monetary policy relative to the no OBC case (row f4). Nor does the OBC have a significant impact on the real allocation. However, the ZLB and the financial constraint together (row f1) constitute a much more significant risk. In this case, the government conducts a permanent credit intervention, cuts the labour tax rate, but maintains a relatively higher nominal interest rate. The government finds this policy mix to be optimal must because the monetary policy is less effective when both OBCs bind simultaneously.

B. *Characterising optimal policy*

To take a closer look at optimal policy, I examine the policy functions of policy instruments and key macroeconomic variables. Figure 2 plots policy functions against the two shocks while other state variables are set to their ergodic median. First, consider the financial shocks shown in the left-hand columns. In the laissez-faire equilibrium (black dash-dot lines), a tightening of the financial constraint has a much larger impact on output than on inflation. Since the monetary policy is inflation targeting, there is only a mild monetary easing (with an order of magnitude of $10^{-2}\%$). By contrast, the optimal monetary policy is considerably more aggressive (red solid lines). When hitting the ZLB, the central bank ramps up asset purchases relative to the case without the ZLB (blue dashed lines). This supports our early claim that monetary policy is less effective when

FIGURE 2. POLICY FUNCTIONS IN THE RAMSEY AND LAISSEZ-FAIRE EQUILIBRIUM



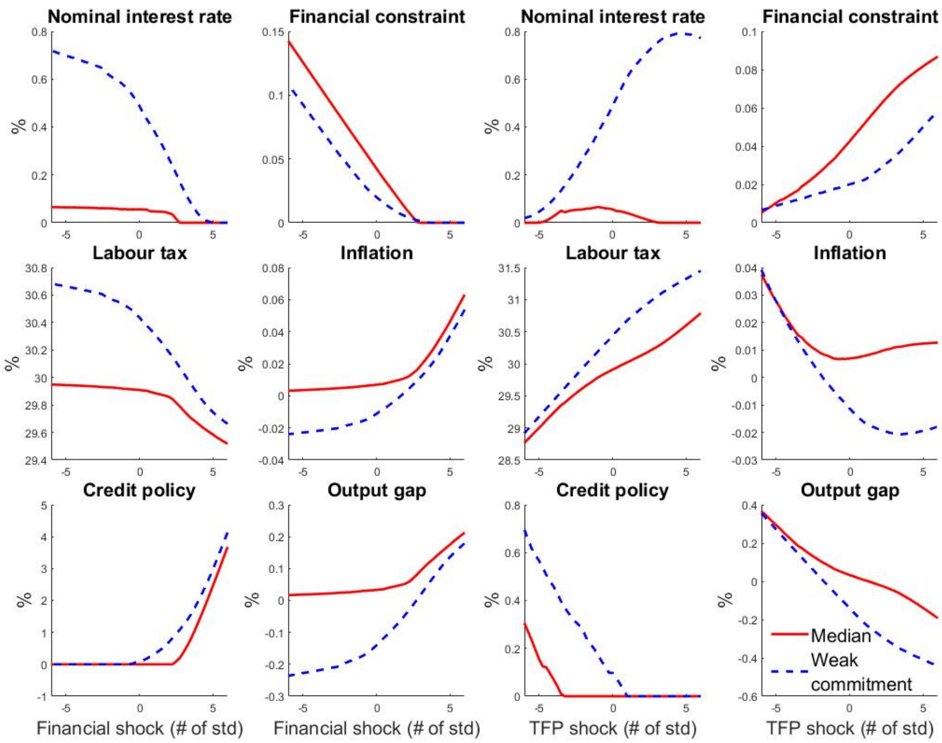
Note: State variables not shown on the x-axes are set to their ergodic median in the Ramsey equilibrium. "LF" denotes the laissez-faire equilibrium. "Ramsey: no zlb" denotes the Ramsey equilibrium without the ZLB. The financial constraint (fc_t) is binding if it equals zero. The output gap is defined as deviations from the output level in the absence of both nominal rigidity and financial frictions.

both the ZLB and the financial constraint are binding. With everything else remaining the same, the benefits of monetary easing at the ZLB (e.g. through a commitment of future interest rates) is limited by the partial transmission from r_t to $r_{k,t}$. For this reason, the risk of hitting the ZLB shifts the optimal nominal interest rate upwards (the red solid line above the blue dashed line). This is in sharp contrast to the literature (e.g. Adam and Billi, 2006), which finds the opposite in models without financial frictions.

Next, consider TFP shocks shown in the right-hand columns. Higher productivity tends to relax the financial constraint thanks to the improved return on bank assets. Meanwhile, the conventional Taylor rule prescribes a decrease in the nominal interest rate to fight deflation pressure. However, when the shock is large enough to render a binding ZLB, the resulting demand shortfall widened suddenly. Consequently, the asset prices fall and the financial constraint binds, thus dragging the economy into the spiral of Fisherian deflation. In the case of a four-standard deviation positive shock (or +1.4%), inflation and output slump by 2.3% and 4%, respectively. Such a catastrophic consequence is largely avoided in the Ramsey equilibrium where the optimal nominal interest rate is a bell-shaped function of TFP shocks.

It is interesting to examine how the government's past commitments restrict today's policy. To this aim, I plot the same policy functions by varying the level of multipliers associated with forward-looking equilibrium conditions. I emphasise the past commitment to ease financial strains, i.e. the multiplier associated with (12). In figure 3, red solid lines are a copy of those shown in 2, with endogenous state variables equal to their ergodic median. Black dash-dot lines are based on the same states except that the multiplier associated with (12) is a standard deviation below

Figure 3. Policy functions under loose and tight commitment constraint



Note: Red solid lines are based on endogenous states equal to their ergodic median. Black dash-dot lines are based on the the same states except that the multiplier associated with (12) is one-standard deviation below the median. The financial constraint (fc_t) is binding if it equals zero. The output gap is defined as deviations from the output level in the absence of both nominal rigidity and financial frictions.

the median. As the government becomes less constrained by its past commitments in the latter case, the nominal interest rate is now an increasing function of productivity almost everywhere, which prevents the economy from falling into a liquidity trap too often. The lack of monetary easing is complemented by a larger asset purchase programme and a higher tax rate to support inflation because the relevant tradeoffs associated with these two policies are more intratemporal than intertemporal. To understand the rather counter-intuitive monetary policy, it is better to examine the full dynamics of the Ramsey equilibrium, which will be shown in the next subsection using an impulse response analysis.

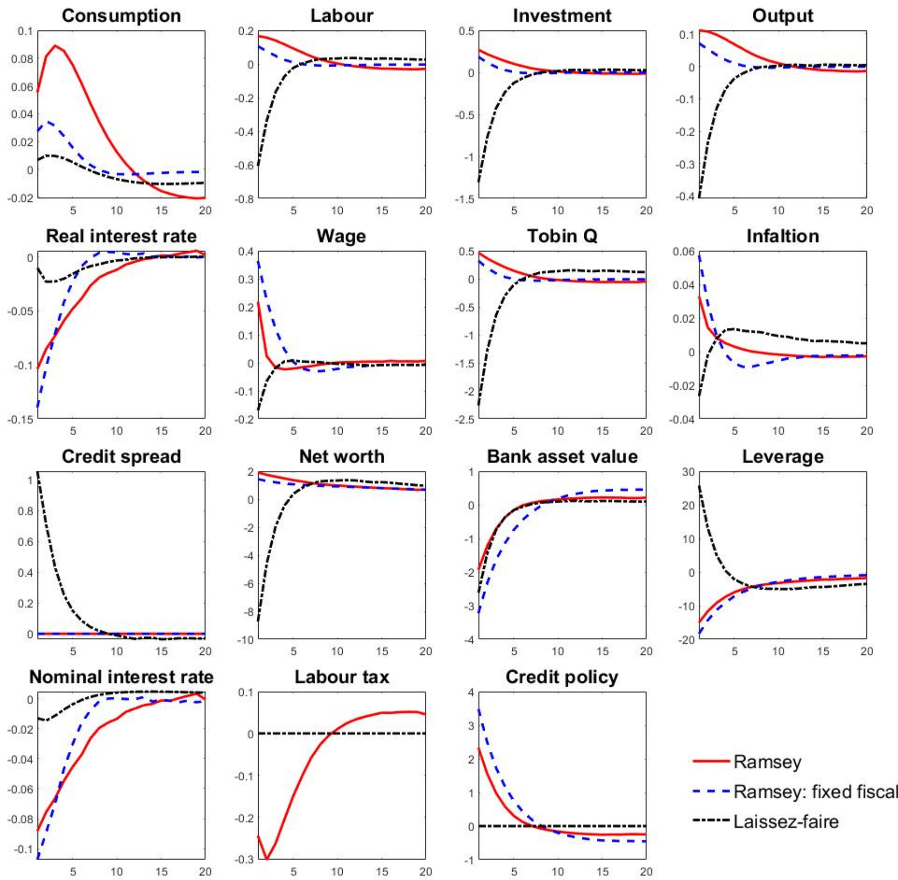
C. Impulse response analysis

I consider impulse responses to a positive financial shock, a positive and a negative TFP shock, all of three standard deviations. Figures 4-6 show the mean expected impulse response functions (generalised IRFs of Koop, Pesaran and Potter, 1996) to each shock as deviations from the stochastic steady state.[21] In each figure, the first to the last rows show real activity, relative prices, financial variables, and policy instruments, respectively.

First consider responses to the financial shock shown in figure 4. Given the binding financial constraint, banks fire sell their assets. In the laissez-faire equilibrium, this makes the asset prices sharply lower, which feeds back into bank net worth and further tightens the financial constraint.

[21] Generalised IRFs are calculated using 500 simulations with 500 periods of burnin. Since the path of the OBCed variable is averaged across varying initial states, the kink is largely smoothed out.

Figure 4. Impulse response to a positive financial shock

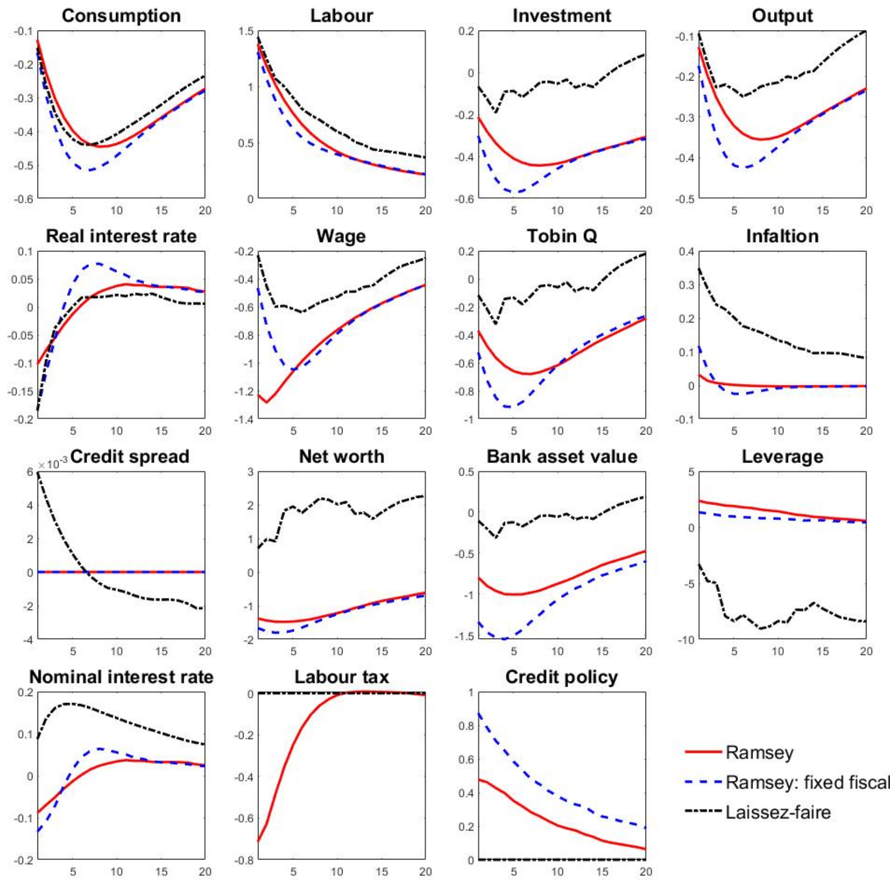


Note: All variables are expressed in percentage point deviations from their stochastic steady state. The size of the shocks is three standard deviations.

The inefficiency in financial intermediation forces households to increase their consumption. The surge in credit spread is supportive towards the marginal cost and inflation. As such, the central bank barely reacts to the shock. The optimal monetary policy focuses more on relaxing the financial constraint by tolerating a modest increase in inflation. Inflation is more manageable when a labour tax rebate stimulates supply. Regarding credit policy, the asset purchase programme is fairly aggressive and unwinds as banks re-leverage. Unlike the laissez-faire equilibrium where banks deleverage slowly, the deleveraging process is instantly completed in the Ramsey equilibrium. This is thanks to the positive policy effects on bank net worth through, respectively, a lower borrowing cost on bank liabilities and a capital gain on bank assets. Note that given a zero credit spread, banks selling assets to the central bank do not negatively affect their profitability.

Upon a negative TFP shock, the capital return should fall in the first best equilibrium (under flexible prices and efficient financial markets) because $z_t = \alpha \frac{y_{m,t}}{k_{m,t-1}} mc_t$ where the marginal cost is a constant. In the presence of nominal rigidity, the real interest rate is generally below its fist best level, meaning that the marginal cost and the capital return are above their first best levels. However, these inefficient adjustments of the economy are beneficial to banks. Therefore, the laissez-faire equilibrium shown in figure 5 features improved net worth and a small credit spread. On the other hand, the Ramsey equilibrium tries to replicate the first best allocation by raising

FIGURE 5. IMPULSE RESPONSE TO A NEGATIVE TFP SHOCK

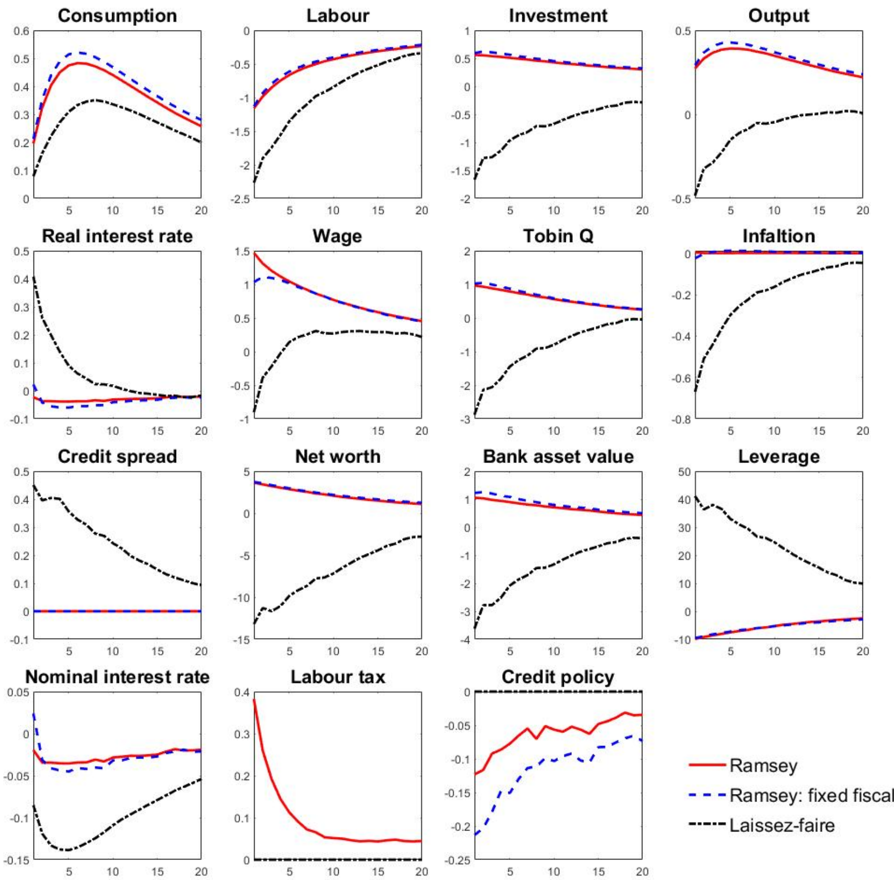


Note: All variables are expressed in percentage point deviations from their stochastic steady state. The size of the shocks is three standard deviations. The response of the laissez-faire equilibrium is volatile because the reported path is the average of a large number of simulations, some of which involve a binding financial constraint and/or the ZLB.

the real interest rate. This is partially achieved by a labour tax rebate, which lowers wages and inflation. Naturally, both a higher real rate and a lower z_t tighten the financial constraint, making it necessary to employ credit policy. At a first glance, figure 5 seems to suggest that the highly expansionary Ramsey policy only worsens the economic performance. But our discussion should make it clear that the Ramsey allocation is in fact closer to the first best allocation. At last, consider a positive TFP shock. As shown earlier, the laissez-faire equilibrium features plunging inflation and output. To avoid this outcome, the key is to lower the real interest rate, which is needed to both stimulate aggregate demand and relax the financial constraint. In other words, there is no tradeoff between inflation stability and financial stability. Here, the Ramsey planner imposes a higher labour tax rate to support inflation while the nominal interest rate is relatively stable. Since the financial constraint is not expected to be binding, the central bank takes this opportunity to reduce its asset holding.

How much does the results so far depend on the government's access to fiscal and credit policy? I solve the Ramsey model with a fixed labour tax rate (blue dashed lines in figure 4-6) and only find minor welfare losses. Without fiscal policy to help stabilise inflation, the contemporary response of monetary policy is more aggressive but the subsequent normalisation is faster. Overall, monetary policy can still manoeuvre the real interest rate in a similar manner. On the other hand, the lack of

FIGURE 6. IMPULSE RESPONSE TO A POSITIVE TFP SHOCK



Note: All variables are expressed in percentage point deviations from their stochastic steady state. The size of the shocks is three standard deviations.

credit policy (not shown) yields large welfare losses.[22] Specifically, the length of the ZLB episodes would be significantly prolonged (doubled under the financial shock) in order to relax the financial constraint.

VI. Simple policy rules

I now consider the implementation of the Ramsey policy using a familiar set of simple rules as below

$$\log \frac{R_t}{\bar{R}} = \max \left\{ \kappa_R \log \frac{R_{t-1}}{\bar{R}} + \kappa_\Pi \log \frac{\Pi_t}{\bar{\Pi}} + \kappa_y \log \frac{y_t}{\bar{y}}, -\log \bar{R} \right\}, \tag{26}$$

$$\mathcal{P}_t = \kappa_{\mathcal{P}} \mathcal{P}_{t-1} + \kappa_{rr} \mathbb{E}_t \left(\log r_{k,t+1} - \log r_{t+1} \right), \tag{27}$$

[22]This case is of less interest since the central bank should always be able to coordinate credit and monetary policy.

where the credit rule is borrowed from Foerster (2015) and the 5 "κ"s are parameters searched numerically to maximise welfare.[23] Searching κ in a 5 dimensional space is extremely costly with OBCs. To make the problem doable, I limit attention to a grid of the parameter space: $\kappa_R \in [0:0.1:3]$, $\kappa_\Pi \in [1:0.1:3]$, $\kappa_y \in [0:0.1:3]$, $\kappa_\mathcal{P} \in [0:0.1:1]$, $\kappa_{rr} \in [0:0.5:5]$, where the expression $[a:s:b]$ denotes the lower bound, the step, and the upper bound. For simplicity, I assume that the tax policy is unresponsive given that adjusting taxes promptly is often difficult. Admittedly, if (26) struggles to stabilise inflation, even a rather naive tax rule may improve welfare considerably. Nevertheless, a comprehensive study of optimal rules is left to future research. As we will see shortly, the conventional Taylor-type rule can do impressively well if equipped with somewhat unconventional parameters.

When the financial constraint is not binding, the optimal rules are arguably similar to those analysed in the literature (e.g. Eggertsson and Woodford, 2003). Therefore, it is most interesting to consider welfare losses conditional on large shocks. To this end, I calculate conditional welfare associated with given rules by simulating the model from the ergodic median of the Ramsey equilibrium under a fixed tax policy. In each simulation, there is only one of the following shocks in the first period: a three-standard deviation positive financial shock, a five-standard deviation negative TFP shock, or a three-standard deviation positive TFP shock. Welfare losses are measured in consumption equivalence λ^c implicitly defined by

$$\mathbb{W}_1\left(\left\{c_t^S - hc_{t-1}^S, l_t^S\right\}_{t\geq 1}\right) = \mathbb{W}_1\left(\left\{(1-\lambda^c)\left(c_t^R - hc_{t-1}^R\right), l_t^R\right\}_{t\geq 1}\right),$$

where $\mathbb{W}_1\left(\left\{c_t^R - hc_{t-1}^R, l_t^R\right\}_{t\geq 1}\right)$ is the welfare evaluated by the contingent plans for consumption and labour in the Ramsey equilibrium (also with a fixed labour tax) in period 1, $\mathbb{W}_1\left(\left\{c_t^S - hc_{t-1}^S, l_t^S\right\}_{t\geq 1}\right)$ is defined similarly for a given set of rules.[24]

TABLE 3—OPTIMISED SIMPLE RULE

Shock	κ_R	κ_Π	κ_y	$\kappa_\mathcal{P}$	κ_{rr}	λ^c(bps)
Financial	1.1	3	0	0.9	5	0.013
Positive TFP	1.1	3	0	0.9	5	0.012
Negative TFP	1.0	3	0	0.9	5	0.014

The optimised rules are reported in table 3 and the welfare surface near the optimal point is illustrated in figure 7. In all cases, the optimal parameters are essentially the same and the associated welfare losses are small.[25] The credit rule features a strong contemporary response to

[23]Note that the responses to inflation and output are not scaled by the degree of persistence $1-\kappa_R$, which is necessary in order to consider superinertial monetary policy, i.e. $\kappa_R >= 1$. Moreover, the monetary rule can be rewritten by introducing a shadow interest rate R_t^*:

$$\log\frac{R_t^*}{\bar{R}} = \kappa_R \log\frac{R_{t-1}^*}{\bar{R}} + \kappa_\Pi \log\frac{\Pi_t}{\bar{\Pi}} + \kappa_y \log\frac{y_t}{\bar{y}},$$

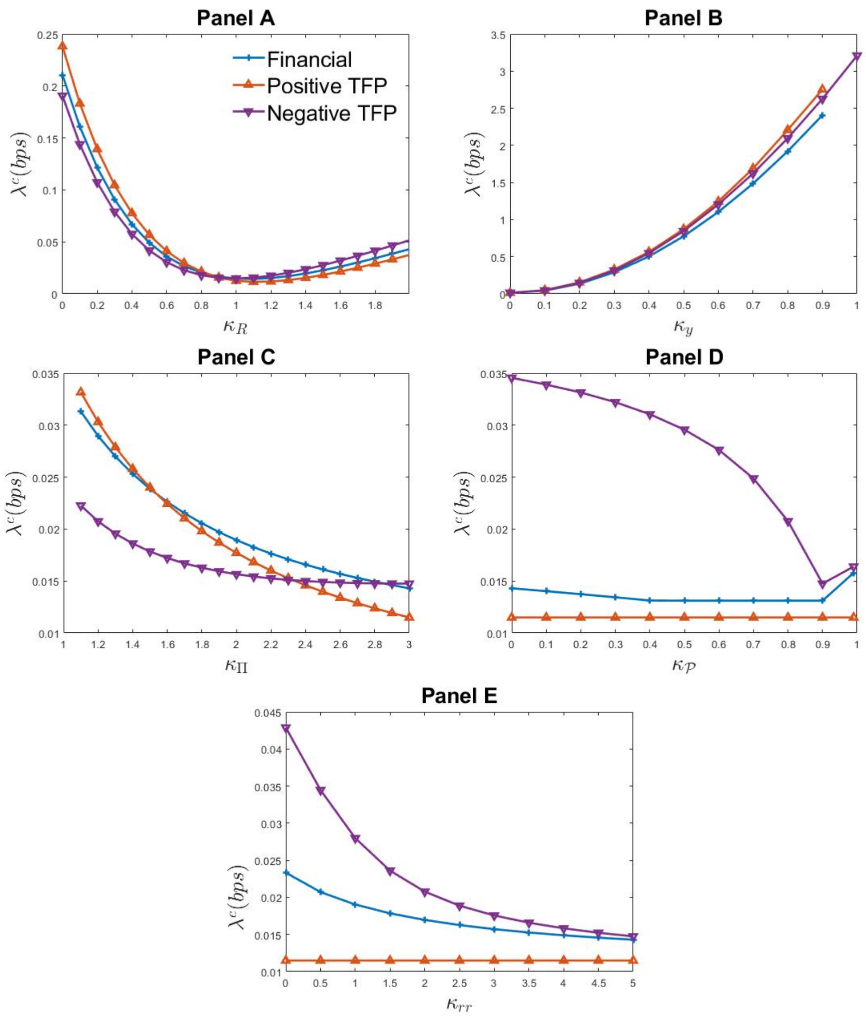
$$\log R_t = \max\left(0, \log R_t^*\right),$$

which is potentially welfare improving at the ZLB. The shadow rule does not change our results because (26) rarely drives the economy to the ZLB regardless of its parameters.

[24]The utility function implies $\lambda^c = 1 - \left(\frac{\mathbb{W}_1^S + \mathbb{W}_1^{Rl}}{\mathbb{W}_1^{Rc}}\right)^{\frac{1}{1-\sigma}}$ where $\mathbb{W}_1^{Rc}$ and $\mathbb{W}_1^{Rl}$ are the discounted (dis)utility of consumption and labour, $\mathbb{W}_1^{Rc} - \mathbb{W}_1^{Rl} = \mathbb{W}_1^R$.

[25]$\kappa_\mathcal{P} \in [0.4, 0.9]$ yields virtually the same level of welfare under the TFP shock. I take $\kappa_\mathcal{P} = 0.9$ for consistency. The variation in κ_R across shocks is due to the fact that the parameter search is done over a grid. A finer search should reveal an optimal κ_R in the range of $[1.0, 1.1]$.

FIGURE 7. WELFARE LOSSES ASSOCIATED WITH SIMPLE RULES NEAR THE OPTIMAL POINT



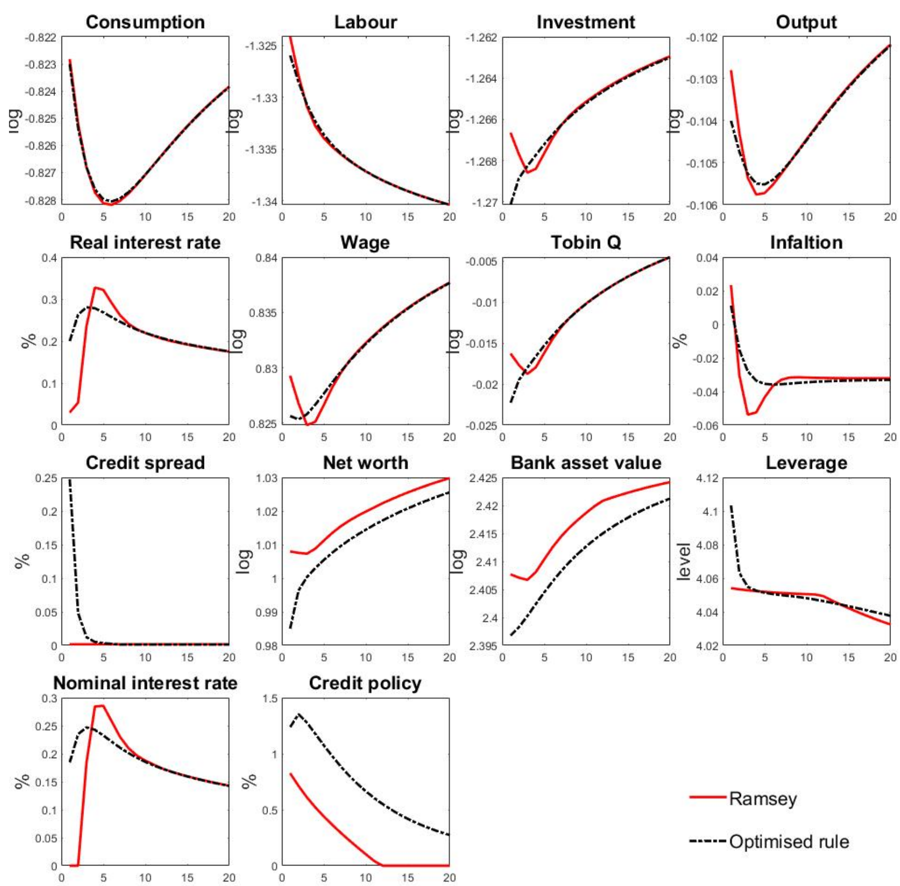
Note: Parameters not shown on the x-axis are set to their optimal values.

the credit spread with substantial persistence. While Foerster (2015) focuses more on extreme cases, i.e. $\kappa_{\mathcal{P}} = 0.99$ and $\kappa_{\mathcal{P}} = 0$, panel D of figure 7 shows that both are suboptimal. Our results on the monetary rule echo a few findings in a standard New Keynesian model (Schmitt-Grohé and Uribe, 2007), including a muted response to output and a strong response to inflation. The inflation coefficient reaches the upper bound of the search grid. But the welfare gains by further increasing the inflation coefficient appear to be limited, especially when there is a tradeoff between financial stability and inflation stability (i.e. under the financial shock and the negative TFP shock, see panel C of figure 7). However, unlike in Schmitt-Grohé and Uribe (2007), the coefficient of monetary policy persistence exceeds but is close to 1, suggesting that the optimal monetary rule is forward-looking and close to price level targeting.

I now take a closer look at how the optimised rules responds to each shock. Upon a positive TFP shock, the simple rule economy can largely replicate the Ramsey allocation. This is thanks to the strong response to inflation embedded in the monetary rule, which helps the economy avoid the financial constraint. Thus, the welfare gains of the optimised rule over the traditional Taylor rule are large as the latter drives the economy into the spiral of Fisherian deflation (recall from subsection V.B). Under both the financial shock and the negative TFP shock, the government faces a tradeoff between financial stability and inflation stability. To best illustrate this point, I show the simulated economy under the negative TFP shock, which raises both the credit spread and inflation. As shown in figure 8, the optimised rules prescribe too strong a credit intervention but insufficient monetary easing. The real interest rate initially raises and hence tightens the financial constraint. Given the positive credit spread, asset purchases have a negative impact on bank net worth by crowding out banks from profitable investment opportunities.

There are potentially two simple ways of easing the policy tradeoff. For example, the government can use a tax policy to restrain inflation. Alternatively, the monetary rule can be augmented to respond to credit spreads.

Figure 8. Simulation under the optimised rule and the Ramsey policy



Note: The starting point of the simulation is the ergodic median of the Ramsey equilibrium except that TFP is five-standard deviation below. The optimised rule contains the following parameters: $\kappa_R = 1.0$, $\kappa_\Pi = 3.0$, $\kappa_y = 0$, $\kappa_{\mathcal{P}} = 0.9$, $\kappa_{rr} = 5$.

VII. Conclusion

I study optimal credit, monetary, and fiscal policy under commitment using a model that is as standard as possible i.e. a New Keynesian model augmented with Gertler and Kiyotaki (2010) style financial frictions. The nonstandard part is that I allow two OBCs, one financial and one on the nominal interest rate. The model is solved in a way that captures the precautionary effect stemming from the nonlinearity of both OBCs, which has two important implications. First, credit policy is permanent in the risky steady state despite being inactive in the deterministic steady state. Second, the government needs to avoid dual binding constraints by keeping the nominal interest rate relatively higher when the ZLB is not binding. I consider a financial shock and a TFP shock and both generate a tradeoff between inflation stability and financial stability even when policymakers have access to all the three policy instruments. The tradeoff is found to be resolved in favour of financial stability with the credit spread being virtually equal to zero under reasonable calibration. The optimal monetary policy is rather counter-intuitive as it can be a bell-shaped or an increasing function of productivity, depending on how much the central bank is constrained by its past commitments. Finally, I find that a familiar set of simple rules can yield small welfare losses but feature too aggressive a credit intervention but insufficient monetary easing.

Several important topics are not covered in this paper. First, the cost of credit policy is not fully captured by our model; see, for example, Borio and Zabai (2016) and Kandrac et al. (2018). The recent work of Cui and Sterk (2018) suggests that credit policy is associated with a considerable welfare cost in terms of inequality. Second, reserves in this model are treated as a perfect substitute for government bonds. There have been many papers (e.g. Christensen and Krogstrup, 2017) studying imperfect asset substitutability, which gives reserves a special role. Third, I leave a full investigation of simple and implementable policy rules to future research.

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Appendix A. The debt Ramsey equilibrium

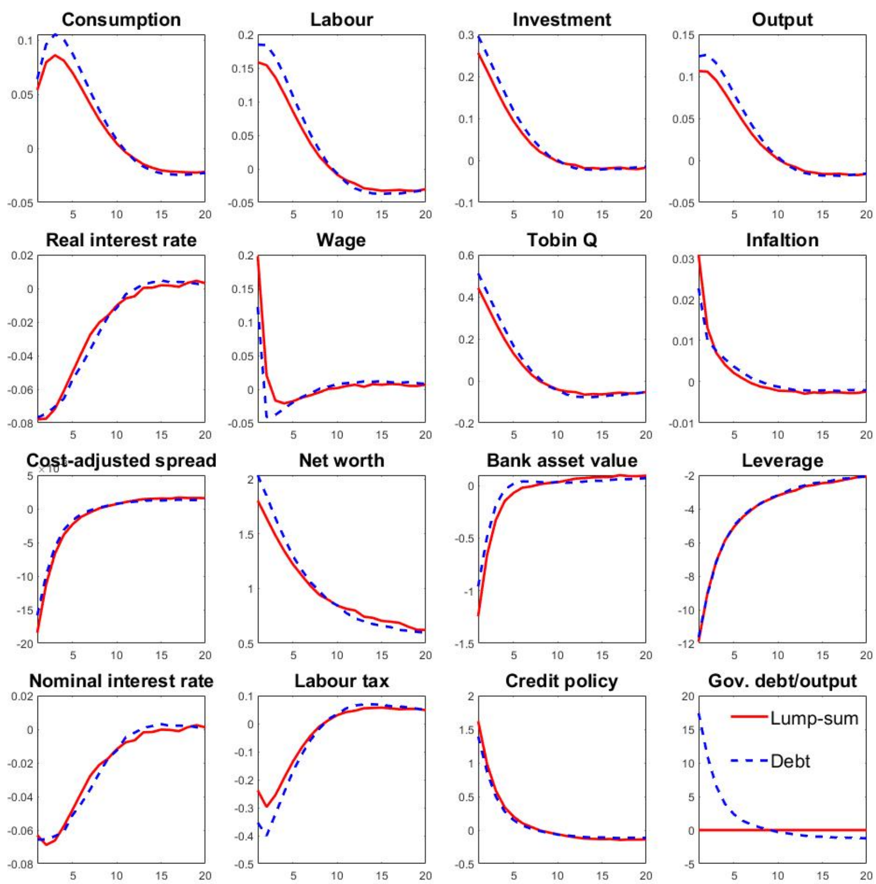
How does the government's asset purchase programme affect its budget constraint? As the government issues government bonds (or reserves) to purchase private assets, the net gain of this operation is given by the credit spread. Recall that the credit spread is close to zero in the Ramsey equilibrium. The zero credit spread, together with the resource cost $\tau_{\mathcal{P}} \left(\mathcal{P}_t q_t s_t\right)^2$, means that the credit policy increases the fiscal burden although the effect might be quantitatively small. This adds interesting tradeoffs to the policy problem but may not be true in reality.[26]

In the literature of optimal monetary and fiscal policy (e.g. Christiano and Kehoe, 1991; Schmitt-Grohé and Uribe, 2004*b*; Siu, 2004, among many others), the problem is how to finance an exogenous government spending shock. On one hand, the government would like to smooth distortionary taxation by using unexpected inflation as a lump-sum tax on nominal wealth. On the other hand, the government would like to stabilise prices in the presence of nominal rigidity. This tradeoff is found to be resolved in favour of price stability. In our model, however, public spending in the form of asset purchases is endogenous and the tax policy can adjust for reasons other than public finance.

Figures A1 and A2 show impulse responses of the lump-sum Ramsey equilibrium and the debt Ramsey equilibrium to shocks that trigger credit policy. The impulse responses are computed without burnin to prevent the debt equilibrium from drifting too far away from the deterministic steady state. The cost-adjusted spread is the credit spread adjusted for the resource cost. Since credit policy generates incomes to finance itself, the debt level moves closely along the government's holding of private assets. The government budget constraint little changes the path of inflation but substantially changes the path of the tax rate. Hence, I conclude that the traditional tradeoff between inflation stability and tax smoothing is still resolved in favour of the former. Particularly, high public debt does not make it difficult to raise interest rates as Evans et al. (2016) suspect.

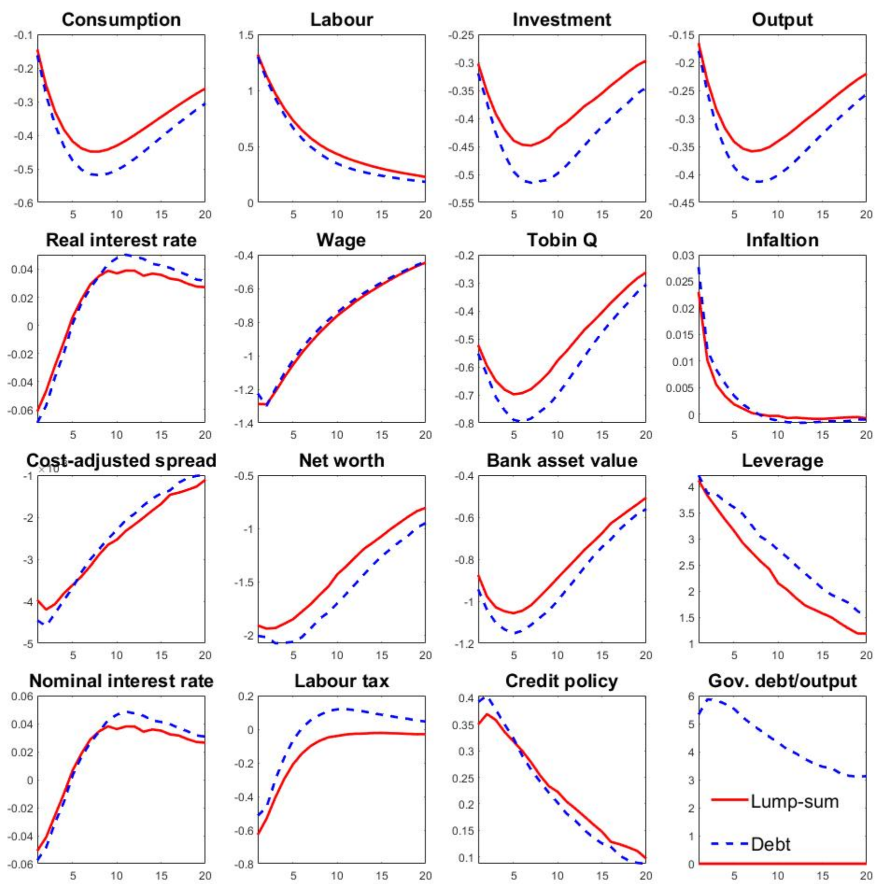
[26]See Reis (2016) for a discussion of this issue.

Figure A1. Impulse response to a positive financial shock



Note: All variables are expressed in percentage point deviations from their stochastic steady state. The size of the shocks is three standard deviations.

FIGURE A2. IMPULSE RESPONSE TO A NEGATIVE TFP SHOCK



Note: All variables are expressed in percentage point deviations from their stochastic steady state. The size of the shocks is three standard deviations.