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QE IN THE FUTURE:
THE CENTRAL BANK'S BALANCE SHEET IN A FISCAL CRISIS

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ABSTRACT

Analysis of quantitative easing (QE) typically focus on the recent past studying the policy's effectiveness during a financial crisis when nominal interest rates are zero. This paper examines instead the usefulness of QE in a future fiscal crisis, modeled as a situation where the fiscal outlook is inconsistent with both stable inflation and no sovereign default. The crisis can lower welfare through two channels, the first via aggregate demand and nominal rigidities, and the second via contractions in credit and disruption in financial markets. Managing the size and composition of the central bank's balance sheet can interfere with each of these channels, stabilizing inflation and economic activity. The power of QE comes from interest-paying reserves being a special public asset, neither substitutable by currency nor by government debt.

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1 Introduction

At the start of the 2008 financial crisis, central banks engaged in unconventional policies, buying many risky assets and giving credit to a wide variety of private agents, but five years later, the balance sheets of the the Bank of England, the Bank of Japan, the ECB, and the Federal Reserve were dominated by only a few items.[1] The liabilities consisted largely of reserves that pay interest, whereas before the crisis there was mostly currency. The assets included foreign currency and short-term securities issued by the government or backed by it, as before, but now also a large stock of longer-term government securities. These changes were the result of quantitative easing (QE) policies, which both increased the size of the balance sheet of the central bank, by issuing banks reserves, as well as its composition, by extending the maturity of the bonds held.[2]

The motivation for these policies was the combination of a financial crisis and zero nominal interest rates, together with the desire to increase liquidity and lower lower long-term yields (Bernanke, 2015). In standard models of monetary policy, QE is neutral, having no effects on inflation or real activity (Wallace, 1981), so new theories were developed to support these policies relying on models where short-term interest rates are zero (Bernanke and Reinhart, 2004) or where financial frictions during crises prevent arbitrage across asset classes and drive changes in term premia (Vayanos and Vila, 2009; Gertler and Karadi, 2013). Yet, the financial crisis is now several years behind and interest rates have already been raised in United States. When this happens, will QE and the use for it disappear, as did so many of the other unconventional monetary policies?

Looking towards the future, this paper asks whether QE would have an effect on macroeconomic outcomes during a fiscal crisis. The focus on a fiscal crisis is motivated by the current data: public debt in the United Kingdom, Japan, many European countries, and the United States is at historically high levels. It is plausible, perhaps even likely, that the next macroeconomic crisis will be fiscal, as suggested by the recent experience in the Euro-area. At the same time, while the literature has focussed on understanding QE after a financial shock, there is no comparable work on the role of QE when the source of the problems is fiscal.

This paper writes down a simple model of fiscal and monetary policy where, in normal

[1]Reis (2009) surveys these unconventional monetary policies.

[2]The literature describing these policies and measuring their impact includes event studies on the responses of yields (e.g., Krishnamurthy and Vissing-Jorgensen, 2011), estimated DSGEs on macroeconomic variables (e.g., Chen, Cúrdia, and Ferrero, 2012), and instrumental-variables regressions on loan supply (e.g., Morais, Peydro, and Ruiz, 2015).

times, QE is neutral. However, during a fiscal crisis, the central bank's management of its balance sheet can have a powerful effect on outcomes through two channels. First, the composition of the central bank's balance sheet alters the composition of the privately-held public debt. In turn, this affects the sensitivity of inflation to fiscal shocks. After a fiscal shock that makes anticipated fiscal surpluses fall short of paying for the outstanding debt, the price level increases to lower the real value of the debt. The maturity of the combined government debt and bank reserves held by the public determines the size and time profile of this bout of inflation. Unexpected inflation lowers welfare directly through price dispersion, and indirectly via aggregate demand and output gaps. QE can reduce these welfare losses.

The second channel comes through the costs of default during a fiscal crisis. Banks suffer losses when government bonds are impaired and, with lower net worth, there is a credit crunch that causes a recession. In anticipation of this default, government bonds start paying a risk premium that lowers their ability to serve as safe collateral. Financial markets may freeze, due to an absence of safe assets, lowering output and welfare. QE can take the risk of default out of the balance sheet of the banks and into the balance sheet of the central bank, reducing the extent of the credit crunch and increasing the effective supply of safe assets.

These channels are new insofar as they have not been used to understand the role of QE. But both of them follow from familiar economic mechanisms in models of inflation, public debt, and financial frictions. What the results in this paper highlight is that interest-paying reserves are a special asset: the central bank is the monopoly issuer of bank reserves, able to freely set their nominal return while ensuring that they are always fully repaid, and they are exclusively held by banks. It is these special features that give QE its power.

I turn next to examine two common criticisms of these policies. Isn't QE just fiscal policy that could be done (and undone) by changes in the profile of issuance of bonds by the fiscal authority? Isn't QE stealth monetary financing of the deficit? Within the model of this paper, I show that the answer to these two questions is a clear no. Interest-paying reserves are not the same asset as either short-term government bonds or currency, so QE is a different policy from debt management or printing money. Moreover, I show that QE is effective regardless of the level of nominal interest rates and in spite of the expectations hypothesis of the term structure of interest rates holding exactly. Therefore, limitations to arbitrage across financial markets or the zero lower bound are not necessary for QE to be effective.

Before concluding, I describe some limitations of QE within the model. In particular, I show that QE may put the solvency of the central bank at risk, induces a redistribution from households to banks, and may require precise targeting of its purchases, especially in an open economy. The conclusion uses these theoretical insights to interpret recent policies.

Aside from its study of QE's channels and limitations, this paper makes three contributions to the literature. First, it provides a model of the standard new Keynesian variety, where monetary policy is not neutral, as surveyed in Woodford (2003), Gali (2008) and Mankiw and Reis (2010), but modified to include working capital so that aside from the usual distortions from nominal rigidities and monopolistic competition, output may also be too low because of capital misallocation. Second, it merges four separate literatures into a simple model by: introducing financial frictions through banks and financial markets following on the footsteps of Gertler and Kiyotaki (2010), Bolton and Jeanne (2011), and Balloch (2015); studying the composition of the central bank's balance sheet following Reis (2013b) and Del Negro and Sims (2015); modeling government debt maturity and its interaction with inflation following Cochrane (2001), Sims (2013) and Leeper and Zhou (2013); and finally by modeling a fiscal crisis as in Uribe (2006) while considering monetary policies as in Cochrane (2014) and Corhay, Kung, and Morales (2015). Third, it highlights the special nature of interest-paying reserves in a monetary system, following a line of work by Hall and Reis (2015a,b).

2 A model of monetary policy and its roles

Because the goal of the model is to highlight economic channels qualitatively, rather than quantify their effect, I make a series of simplifying assumptions that reduce the scope for dynamics to not last beyond two consecutive periods. In particular, I assume that: long-term bonds have a maturity of two periods, price stickiness lasts for only one period, and working capital fully depreciates within one period. Each of these assumptions could be relaxed by future research, but for now they serve the useful purpose of constraining the effects of QE to at most two periods. The full model is laid out mathematically in appendix A, while here I highlight its key components by presenting the two government agencies, the fiscal and monetary authorities, and the private economy made up of consumers, firms, and financial institutions.

2.1 The fiscal authorities

In reality, governments issue liabilities of many different kinds. However, central banks focus their operations on the more liquid government bonds, in part so that their value can be inferred from market prices, and in part so that they can be sold quickly if needed. Of these liquid assets, the more dominant are nominal bonds of different maturities. While the maturity structure of the outstanding public debt can be complex, in the model I simplify by considering only two types: short-term (1-period) and long-term (2-period) bonds. The face value of bonds outstanding at date t that mature in one period is denoted by b_t and they trade for price q_t. These include both long-term bonds issued at $t-1$ as well as short-term bonds just issued, since they are equivalent from the perspective of date t. Long-term bonds issued at date t trade at price Q_t and pay B_t at $t+2$. These prices are in nominal units, and the price level is p_t.

The government has real expenditures of an exogenous amount g_t, and must fund them through two sources of revenue. The first are real dividends from the central bank d_t. The second are fiscal revenues from taxation, f_t, which the government can choose. The distortionary effects of taxation are typically modeled through a convex Laffer curve that has some peak at a fiscal limit $\bar{f}_t$, the upper bound on what the government can collect from its citizens without leading to widespread tax evasion and avoidance. I model this Laffer curve in a simpler and starker way: the fiscal authority can costlessly choose any $f_t < \bar{f}_t$ as a lump-sum revenue, but it is infinitely costly to generate higher fiscal surpluses.

Combining these ingredients, the government flow budget is:

$$\delta_t(b_{t-1} + q_t B_{t-1}) = p_t(d_t + f_t - g_t) + q_t b_t + Q_t B_t. \tag{1}$$

The variable $\delta_t \in [0, 1]$ is the repayment rate at date t on bonds that were outstanding. When $\delta_t = 1$, debts are honored. Otherwise, $1 - \delta_t$ is the haircut suffered by the bondholders.[3]

Fiscal policy consists of picking taxes $\{f_t\}$ and debt management $\{\delta_t, b_t, B_t\}$, which includes both whether and how much to repay old debts, as well as how to manage the maturity of outstanding debt.

[3] The repayment rate is the same for the two types of bonds. Therefore, there will be no difference in the model between servicing the debt or redeeming it. Future work can explore this distinction.

2.2 The central bank

The central bank's main liability, and the main tool in implementing monetary policy in all modern central banks, is the amount of nominal reserves v_t. Reserves pay an interest rate that is set by the central bank i_t.

These reserves finance the central bank's holdings of the two government bonds, b_t^c and B_t^c, as well as the gap between the dividend that the central bank pays the fiscal authority, d_t, and the seignorage revenue it earns from issuing currency minus central bank expenses. While higher inflation affects seignorage, both by debasing its real value and by affecting the desire to hold currency, Hilscher, Raviv, and Reis (2014b) find empirically that the elasticity of seignorage with respect to inflation is quite small. For simplicity, I take seignorage net of expenses s_t to be exogenous.[4]

Combining all these ingredients, the flow budget of the central bank is:

$$v_t - v_{t-1} = i_{t-1}v_{t-1} + q_t b_t^c + Q_t B_t^c - \delta_t(b_{t-1}^c + q_t B_{t-1}^c) + p_t(d_t - s_t). \tag{2}$$

Monetary policy consists of choices of the interest rate paid on reserves $\{i_t\}$ and balance-sheet policies $\{v_t, b_t^c, B_t^c\}$. Some of these may follow rules, they do not need to be exogenous. For instance, the central bank could choose to issue zero reserves and hold zero bonds, while still setting interest rates and rebating seignorage in full every period. This is the typical case considered in studies of monetary policy (Woodford, 2003).

2.3 Financial markets: the interbank market

This paper models financial markets not as a vehicle to transfer resources over time, but as playing the role of capital allocation, moving resources from those who have no production possibilities to those with projects. Working capital comes in the form of an endowment that the economy receives every period and that fully depreciates within the period. This capital can either be turned one-to-one into consumption, or used to produce varieties of goods. However, capital must make its way to the firms through a financial system with frictions. In period $t-1$, the ownership of next period's working capital is split with a fraction κ belonging to banks, while the remaining $1-\kappa$ belongs to households. Banks are randomly drawn i.i.d. from the household every period, so that they only effectively operate separately

[4]This assumption excludes a familiar mechanism: that higher inflation may raise seignorage and so relax the fiscal constraint faced by the government. This effect is both quantitatively small and qualitatively well understood (Sargent and Wallace, 1981).

from the household for two periods.[5]

In their first period of life, $t-1$, banks meet each other in an interbank market, similar to the one in Bolton and Jeanne (2011) and Balloch (2015). In particular, only a fraction ω of the banks will be matched with firms and productive possibilities next period, while the remaining $1-\omega$ can only trade in financial markets. Banks without opportunities could sell their claim on working capital for reserves at the central bank or for government bonds. Alternatively, they could lend to the productive banks in the interbank market, and since they are perfectly competitive, the interest rate in that market is $1+i_{t-1}$. The feasibility constraint on interbank lending is: $x_t \leq (1-\omega)\kappa$.

Aside from their ownership of claims on working capital, the good banks can also buy government bonds or reserves. In equilibrium, they would not want to do so, since the return on lending the working capital out to firms is higher. Yet, with the amount x_t they receive in interbank loans, the good banks can only commit to repay back a share $\xi \leq 1$. Between periods, they can run away with a share $1-\xi$ of the interbank loans, and this action is not verifiable by the other banks, so they cannot stop it. However, running away leads the bank to lose ownership of its marketable assets, which the creditors can seize. Therefore, the incentive constraint for them to repay the interbank loans is:

$$(1-\xi)x_t \leq q_{t-1}b^p_{t-1} + v_{t-1}, \tag{3}$$

where b^p_{t-1} are the bond holdings by borrowing banks, which can be sold next period. With a large ξ, the relevant case, banks hold only little collateral allowing them to borrow large amounts in interbank markets.[6]

2.4 Financial markets: deposits and credit

At the start of the period t, all uncertainty is realized, and the productive banks find themselves with $\omega\kappa + x_t$ claims on working capital available. Interbank markets are senior to all other claims so, as long as the incentive constraint holds, then the unproductive banks get paid, so the productive banks bear all the losses that may arise from default on the collateral they held. Therefore, their net worth after paying the claims in the interbank market, and

[5] This assumption implies that banks do not accumulate net worth over time. This simplifies the analysis by restraining the effect of shocks to bank equity to one period.

[6] One can associate this interbank market with the repo market and read ξ as a measure of the haircut on government debt in that market. More generally, this market can be interpreted as the market where financial institutions lend to each other and need safe assets to facilitate this trade.

before approaching households in the deposit market, is equal to their endowment of capital minus the loss incurred on the collateral relative to the interbank loan: $n_t = \omega\kappa_t - b^p_{t-1}(1-\delta_t)$.

The banks can raise more working capital in the deposit market, where they deal with households, and I model this following Gertler and Kiyotaki (2010). Deposits, z_t, face a feasibility constraint $z_t \leq 1 - \kappa$. Since the households can transform their working capital into consumption one-for-one and they behave competitively, the return on deposits is 1.[7]

Aside from feasibility though, there is also an incentive constraint. Banks can only pledge a share γ of their revenues, but can abscond with the remainder. For them to choose not to do so, the return from absconding with funds must be lower than that from paying depositors in full:

$$(1-\gamma)(1+r_t)(n_t+z_t) \leq (1+r_t)(n_t+z_t) - z_t. \tag{4}$$

The combined effect of the two frictions, in interbank and deposit markets, is that the unit of working capital available in the economy will end up funding only k_t projects, which is the sum of the working capital in productive banks, the capital raised in interbank markets, plus the amount raised as deposits, net of losses in the collateral portfolio.

2.5 Households

A representative household has preferences given by:

$$\mathbb{E}_t\left[\sum_{\tau=0}^{\infty}\beta^{\tau}u\left(c_{t+\tau}+g_{t+\tau}-\frac{l_{t+\tau}^{1+\alpha}}{1+\alpha}\right)\right], \tag{5}$$

where $u(.) : \mathbb{R}^+ \to \mathbb{R}$ with $u'(.) \geq 0$ and $u''(.) \leq 0$ is the household's utility function, c_t is aggregate consumption and l_t are hours worked. The particular functional form inside the utility function implies that private consumption and public services are perfect substitutes. This simplification avoids dealing with how to value these different goods, which are not the subject of this paper, and makes households indifferent as to the size of government. Moreover, it implies that $1/\alpha$ is the wage elasticity of labor supply and there are no income effects on hours worked.

Because households can choose to hold the two bonds across periods, a no-arbitrage

[7]With a return of 1, the household is indifferent between depositing working capital in the bank or simply transforming it into consumption. One should interpret the return on deposits as infinitesimally above 1 to break this indifference and make households want to deposit all their capital in the banking system.

condition holds:

$$\mathbb{E}_t\left(\frac{m_{t,t+1}\delta_{t+1}p_t}{q_t p_{t+1}}\right) = \mathbb{E}_t\left(\frac{m_{t,t+2}\delta_{t+1}\delta_{t+2}p_t}{Q_t p_{t+2}}\right) = 1. \tag{6}$$

The stochastic discount factor is, as usual, equal to the discounted marginal utility in the future as a ratio of marginal utility today: $m_{t,t+\tau} = \beta^\tau u'(c_{t+\tau} + ...)/u'(c_t + ...)$. These no-arbitrage conditions could be log-linearized to yield the usual Euler equation, or IS curve, in monetary models.

2.6 Firms

There is a single final good, produced by a competitive firm, that results from aggregating a continuum of varieties of goods:

$$y_t = \left(k_t^\theta \int_0^{k_t} y_t(j)^{\frac{\sigma-1}{\sigma}} dj\right)^{\frac{\sigma}{\sigma-1}}, \tag{7}$$

where $\sigma > 1$ is the elasticity of demand for each variety. The measure of varieties available for production is denoted by $k_t \in [0, 1]$, with the strength of this "love for variety" or "congestion externality" determined by the parameter θ.

Each variety can be produced by a single monopolistic firm only if it has one unit of working capital. Therefore the number of varieties is the same as the amount of capital employed in the economy, or the measure of firms in operation.[8] Working capital is available from banks for rental at price $1 + r_t$, and because of free entry, this payment just covers the profits of firms.

Otherwise, firm behavior is just like in the textbook new Keynesian model. The firms' maximization is subject to the demand for their good and to the technology: $y_t(j) = a_t l_t(j)$, where $l_t(j)$ is the labor used and a_t is productivity. Standard calculations show that the desired optimal price, p_t^* is a constant markup over marginal cost, determined by the nominal wage w_t. However, only a fraction λ of firms can choose their price equal to their desired level. The remainder must choose their prices p_t^{*e} with one-period old information.[9]

This simple model of nominal rigidities has the two usual implications. First, there is

[8]This treatment of capital may seem different from what is usual in the literature, where capital is often a variable factor of production. Yet, if $k_t = 1$, which will be the first best, this setup of production is identical to that in the textbook new Keynesian model without capital. The important assumption here is rather that capital cannot be accumulated over time, unlike in the neoclassical growth model.

[9]This canonical model does not require taking a stand on what is the best model of time-dependent price adjustment, since with one-period nominal rigidities, there is little difference between sticky information and sticky prices.

a Phillips curve linking unexpected inflation to real activity, which in log-linearized terms equals:[10]

$$\hat{p}_t - \hat{p}_{t-1} = \mathbb{E}_{t-1}(\hat{p}_t - \hat{p}_{t-1}) + \frac{1-\lambda}{\lambda}(\alpha \hat{l}_t - \hat{a}_t). \tag{8}$$

Second, because all firms are ex ante identical, this price dispersion is an inefficiency that leads to under-production. Aggregating across firms, $y_t k_t^{\frac{1+\sigma\theta}{1-\sigma}} \Delta_t = a_t l_t$ where:

$$\Delta_t \equiv k_t^{\frac{1+\sigma\theta}{1-1/\sigma}} \left(\frac{p_t^*}{p_t}\right)^{-\sigma} \left[\lambda + (1-\lambda)\left(\frac{p_t^{*e}}{p_t^*}\right)^{-\sigma}\right], \tag{9}$$

so that $\Delta_t \geq 1$ is a measure of price dispersion, minimized at 1 when there are no inflation surprises and so $p_t^{*e} = p_t^*$.

2.7 Equilibrium and the conventional benchmarks

An equilibrium is a collection of outcomes in goods markets $\{c_t, y_t, y_t(j), p_t, p_t(j)\}$, in labor markets $\{l_t, l_t(j), w_t\}$, in the credit, deposit and interbank markets $\{r_t, k_t, x_t, z_t, b_t^p\}$, and in bond markets $\{q_t, Q_t\}$, such that all agents behave optimally and all markets clear, and given exogenous processes for $\{\bar{f}_t, s_t, a_t, g_t\}$ together with choices for fiscal policy $\{f_t, \delta_t, b_t, B_t\}$ and monetary policy $\{i_t, v_t, b_t^c, B_t^c\}$. Appendix A spells out the equations defining equilibrium.

If there is no default and the incentive constraints in the capital markets do not bind, then $k_t = 1$ so that all working capital is employed. In this case, the model is a standard new Keynesian model. On the side of the private sector, there is a Phillips curve linking output to the surprises in the price level and an Euler equation linking output growth to the real interest rate. On the side of the government, the budgets of the fiscal and monetary authorities can be collapsed into one, Ricardian equivalence holds, so bond holdings or reserves have no effect on equilibrium. With a standard rule for interest rates, like the Taylor rule and a Ricardian policy of choosing fiscal surpluses to pay for existing debts, then the price level would likewise be determined just as in the standard analysis in Woodford (2003), Gali (2008) or Mankiw and Reis (2010).

[10] In solving the model later, no log-linearizations will be used.

3 Fiscal crisis and quantitative easing policies

The model of the previous section is a fully specified DSGE. One could solve it numerically, and quantitatively evaluate the effect of different balance-sheet policies in response to shocks to fiscal capacity, productivity, government spending or interest rates. Leaving that for future research, the approach that I will take is instead to simplify the uncertainty in the model to focus on fiscal crises and on a restricted set of policies, QE.

3.1 The fiscal crisis

A *fiscal crisis* is an exogenous contraction in $\bar{f}_t$. At date 0 everyone unexpectedly learns that the fiscal limit at date 1 may be lower. This right away triggers a crisis, whether default materializes at date 1 or not. At date 1, with probability $1-\pi$, $\bar{f}_1 = \bar{f} - \phi$, while otherwise $\bar{f}_1 = \bar{f}$. The two key parameters describing the fiscal crisis are then π, capturing its likelihood from the perspective of date 0, and ϕ capturing the severity of the crisis at date 1. The following holds:

Assumption 1: *The initial conditions on government liabilities are:*

1. $v_{-1}/\beta + b_{-1} - b^c_{-1} + \beta(B_{-1} - B^c_{-1}) \leq (\bar{f} + s - g)/(1-\beta)$.

2. $\beta\phi \geq (\bar{f} + s - g)/(1-\beta) - [v_{-1}/\beta + b_{-1} - b^c_{-1} + \beta(B_{-1} - B^c_{-1})]$.

The first assumption on the initial debt ensures that, bar a fiscal crisis, the government is able to pay its debts. The second assumption on the size of the fiscal shortfall ensures that in a fiscal crisis, the shortfall in revenue relative to spending is such that it will require a default in public debt or an increase in inflation to restore the intertemporal budget constraint of the government. As long as the size of the crisis is large enough, or ϕ is sufficiently large, an outcome when there is no default and price stability is impossible in equilibrium.

For simplicity, the fiscal crisis is the only source of uncertainty in the economy. That is, I assume that productivity, seignorage, and government spending are all known and, without loss generality, they are constant at a, s, g, respectively. Moreover, after date 1, there is no more uncertainty as the fiscal limit is equal to a constant $\bar{f}$. Considering multiple shocks over multiple periods would be useful to learn about the quantitative dynamics of the fiscal crisis and QE, but here I focus on characterizing the two new qualitative channels.

3.2 Quantitative easing

Quantitative easing policies, the focus of this paper, consist of changes in the central bank's balance sheet such that changes in reserves v_t are exactly equal to changes in the bonds held by the central bank: $b_t^c + Q_t B_t^c$. They are the twin choices of how many reserves to issue, and what maturity of government bonds to acquire with them.

Keeping the focus on QE, I make a conventional assumption for the other monetary policy choices. The central bank chooses interest rates to be consistent with a price level target of $p_t = 1$, as long as this is consistent with the existence of an equilibrium. It is well known that in this class of models, a price-level target is optimal (Reis, 2013a), and setting it to the constant 1 is just a useful simplification. Given this policy, I further assume that the initial conditions for prices and expectations are: $\mathbb{E}_{-1}(p_0) = p_{-1} = 1$.

3.3 A final set of assumptions

With risk averse agents, the maturity of the government liabilities held by the private sector could be used to provide insurance against the risk of inflation (e.g. Lustig, Sleet, and Yeltekin, 2008). This channel has been explored in the literature on the optimal maturity of government debt, and it is likely not very relevant to reserves, which in reality are overnight liabilities. To separate the new effects studied in this paper from this provision of insurance, I assume that preferences are risk neutral, so the $u(.)$ function is linear.

This assumption also implies that the stochastic discount factor is constant: $m_{t,t+\tau} = \beta^\tau$, so that the equilibrium can be solved exactly, without needing to approximate the equilibrium relations because of risk premia. Moreover, it ensures that there are no risk premium of any type in holding bonds of different maturities. Therefore, the term structure hypothesis holds exactly, and we can be sure that none of the results are driven by the breakdowns in arbitrage that the previous literature on QE has focussed on. Finally, linearity implies that welfare is proportional to the amount of output produced in the economy, making it easier and more transparent to solve for optimal policies.

A final set of parameter restrictions makes sure that the focus is on equilibria of the model that are interesting for the question in this paper:

Assumption 2: *The following parameter restrictions hold:*

1. $a^{1+1/\alpha} \geq \left(\frac{\sigma-1}{1+\theta\sigma}\right)$.

2. $\theta = (1 - 1/\sigma)/(1 + 1/\alpha) - 1/\sigma$.

The first assumption guarantees that productivity is high enough so that it is socially optimal to use working capital for production rather than consumption.

The second assumption is more peculiar and deserves some explanation. It fixes the love for variety as a precise formula of the elasticities of product demand and labor supply. It is well known that in monopolistic competition models like this one, the profits of an individual firm may increase or decrease as more firms enter the market. On the one hand, as more firms enter, the demand for each variety declines, keeping total spending fixed. On the other hand, total output increases because of an externality, since more varieties produced raise overall welfare and demand for all goods. The parameter θ controls the strength of this second effect relative to the first. Making this particular assumption on its value results in the return on each firm earned by the bank, r_t being constant. This simplifies the analysis considerably, while losing little in terms of the generality of the results.

3.4 Welfare

Appendix B proves that welfare in the economy depends on the output gap and inflation, just as in standard new Keynesian economies:

Lemma 1. *Letting $y_t^* = a^{(1+1/\alpha)}$ be the first-best level of output, and $k^* = 1$ be the first best level of working capital, welfare in this economy at date t is:*

$$\mathbb{E}_t \sum_{\tau=0}^{\infty} \beta^\tau y_{t+\tau}^* \left[\frac{y_{t+\tau} - k_{t+\tau} + k^*}{y_{t+\tau}^*} - \left(\frac{y_{t+\tau}}{y_{t+\tau}^*} \right)^{1+\alpha} \frac{k_{t+\tau}^{-\alpha} \Delta_{t+\tau}^{1+\alpha}}{1+\alpha} \right]. \tag{10}$$

If prices are flexible ($\Delta_t = 1$), then welfare every period is an increasing linear function of k_t. If capital markets are efficient ($k_t = k^*$), then stabilizing prices achieves the "divine coincidence" of both eliminating price dispersion ($\Delta_t = 1$) and the output gap ($y_t = y_t^*$).

Welfare in this economy depends on the total amount of output that is produced, and this in turn depends on how much working capital is available to firms and on how well allocated is labor across them. When all capital is employed ($k_t = k_t^* \equiv 1$) and there are no surprises distorting the setting of prices by firms ($\Delta_t = 1$), welfare is maximized. Lower interbank lending lowers output by locking working capital in banks that do not have access to lending opportunities. Lower deposits lower output by locking working capital in households. Both prevent valuable working capital from reaching the firms that could put it to productive use. Unexpected inflation lowers output by making some firms make pricing mistakes, inducing price dispersion and misallocation of labor.

If there was no collateral constraint in interbank markets, no skin-in-the game constraint in the deposit market, and no price rigidity, then this economy would achieve the first best (subject to the monopolist distortion). That is, if $\lambda = \xi = \gamma = 1$, the equilibrium would be efficient, regardless of fiscal and monetary policy. Otherwise, after a fiscal shock, welfare may be lower because of the three frictions in the economy: nominal rigidities by firms leading to price dispersion, credit frictions in collecting funds from depositors, and liquidity frictions in the interbank market.

4 The neutrality of QE

While the goal is to investigate the circumstances under which QE may have an effect, it is useful to start from the opposite perspective, when QE is neutral. Within the model in this paper, there are two benchmarks of neutrality that correspond to the bulk of the literature on central bank balance sheets (Eggertsson and Woodford, 2003; Benigno and Nistico, 2015).

4.1 QE in normal times

The case where there is no fiscal crisis corresponds to $\phi = 0$, so that the fiscal limit is unchanged in period 1 (and the probability of a crisis, π, becomes irrelevant). Still, the fiscal authority must choose a combination of fiscal surpluses and debt management $\{f_t, b_t, B_t\}$, while the monetary authority chooses the size and composition of its balance sheet $\{v_t, b_t^c, B_t^c\}$. Appendix D proves that:

Proposition 1. *If $\phi = 0$, the fiscal authority chooses f_t so that $f_t = (1-\beta)(v_{-1}/\beta + b_{-1} - b_{-1}^c + \beta B_{-1} - \beta B_{-1}^c) - s + g$ at all dates, and issues enough bonds $\beta b_t \geq (1-\xi)(1-\omega)\kappa$ at all dates, then the economy reaches the efficient outcome regardless of the QE policy of the central bank.*

Intuitively, the fiscal authority chooses fiscal surpluses to pay for the debt preventing any default, and issues enough bonds so that the interbank market can function. Since there no shocks, there are no price surprises and no price dispersion. Therefore, the economy reaches the first best, independently of the choices of reserves and bond holdings by the central bank, $\{v_t, b_t^c, B_t^c\}$. QE is neutral in normal times.

Why is this the case? When the central bank buys government bonds with reserves, it is only exchanging one type of government liability for another. Short-term bonds and reserves are perfectly equivalent, as are long-term bonds since they can be traded next period with no risk. Therefore, QE has no effect on the solvency of the government, on its ability to pay its debts, and therefore on the price level or on the likelihood of default.

Mathematically, this can be seen because the consolidated government budget constraint at all dates is equal to:

$$\frac{(1+i_{t-1})v_{t-1}+\delta_t[b_{t-1}-b^c_{t-1}+q_t(B_{t-1}-B^c_{t-1})]}{p_t}=\left[\sum_{\tau=0}^{\infty}\beta^{\tau}(f_{t+\tau}-g+s)\right]. \tag{11}$$

Any QE policy consist of exchanging reserves for government bonds. But, the arbitrage condition linking i_t, q_t and Q_t ensures that as long as there is no fiscal crisis and no default, then such a purchase would leave the left hand side of this expression unchanged.

In turn, in credit markets, reserves can be equally used as government bonds in the interbank market. If banks have enough short-run bonds to satisfy their needs in interbank markets, then no supply of reserves in exchange for these bonds has an effect on the credit constraints. Again, the two types of government liabilities are perfect substitutes, so that QE has no effect on the amount of credit in the economy or on the efficiency with which working capital is allocated.

4.2 Wallace neutrality

Another useful benchmark applies even to circumstances when there is a fiscal crisis. As emphasized by Wallace (1981) and Chamley and Polemarchakis (1984), short-term bonds and reserves are just two forms of government liabilities. Each is denominated in nominal terms and each promises a certain nominal return next period. Therefore, one would expect that open market operations, which trade reserves for short-term bonds, have no effect on equilibrium outcomes. In the model, if there is no default, so $\delta_t = 1$ at all dates, in all the equilibrium conditions only the sum $v_t + q_t b_t$ appears even during a fiscal crisis. Therefore, exchanging reserves for short-terms bonds is neutral. This equivalence no longer holds if the fiscal crisis can lead to default, since one of these securities may default while the other one does not.

5 The economy in a fiscal crisis

Given a fiscal crisis, the government must choose the level of taxation f_t. While either default or inflation are inevitable, higher tax collections will lower either of these and raise welfare.

Therefore, the fiscal authority optimally chooses $f_t = \bar{f}_t$ at all dates.

Aside from taxation, the fiscal authorities can also opt for one of two regimes (or an in between). Either they commit to never defaulting on government bonds, so $\delta_t = 1$ at all dates, and the central bank has to choose the nominal interest rate to adjust to the resulting path for the price level. This is sometimes called a fiscal dominance or non-Ricardian policy regime. Or, the central bank stays committed to the price level target $p_t = 1$ at all dates, but the fiscal authority defaults on its bonds.

After the fiscal crisis is in the past, this choice is immaterial for the equilibrium of the economy or the effectiveness of QE. Policymakers could always set policy to generate inflation or default, but this would at best be neutral and at worst potentially lower welfare. Appendix C shows that the equilibrium is:

Proposition 2. *Given assumptions 1 and 2, the equilibrium at all dates $t \geq 2$ is consistent with both stable prices $p_t = 1$ and no default $\delta_t = 1$. The economy reaches the first best: $k_t = 1$ and $\Delta_t = 1$.*

The analysis of QE at date 2 is similar to the previous section. The intertemporal government budget constraint at date 2 is:

$$\frac{v_1}{\beta} + \delta_2 \left[b_1 - b_1^c + \beta(B_1 - B_1^c)\right] = p_2 \left(\frac{\bar{f} - g + s}{1 - \beta}\right). \tag{12}$$

If the central bank issues one more unit of reserves, it can buy either $1/\delta_2\beta$ more short-term bonds or $1/\delta_2\beta^2$ more long-term bonds, since $\delta_2\beta$ and $\delta_2\beta^2$ are the equilibrium prices of short-term and long-term bonds, respectively. Therefore, QE leaves the left-hand side of this equation unchanged. Any QE policy is consistent with the price level target of $p_2 = 1$ and the no default choice $\delta_2 = 1$. Because v_1 is chosen at date 1, this neutral QE happens while the economy is experiencing the fiscal shock.

However, at date 0 when there is a fiscal crisis that may or may not materialize next period, QE is not neutral. Appendix E shows that it is easy to numerically solve for the equilibrium in this economy:

Proposition 3. *For a given δ_1, the intertemporal budget constraint of the government provides three equations that pin down p_0 and p_1 at the two states of the world. In turn, equilibrium in capital markets with binding incentive constraints solves for k_1 as a function of δ_1. Then, given p_0, p_1, k all other variables are pinned down by solving 13 equations in 13 unknowns.*

In practice, an algorithm that for each choice of δ_1 in a grid in $[0,1]$ solves these equations, will quickly deliver all of the (δ_1, p_1) equilibrium combinations and the full set of outcomes in each of these equilibria. Since the goal of this paper is not to provide quantitative predictions, but to highlight new theoretical channels, I leave for future research the task of numerically investigating this equilibrium. Instead, the next section focuses on the case where $\delta_1 = 0$, while the following section covers the case where $p_1 = 1$. These two polar cases provide a clean separation of the two channels through which QE is not neutral in this economy.

6 The effect of QE on inflation and aggregate demand

In this section, assume that the fiscal authority stays committed to not defaulting, so $\delta_1 = 0$. In a fiscal crisis, the price level must deviate from target to inflate away the public debt.

Let p_1' denote the price level if there is a crisis and p_1'' if there is no crisis. They are pinned down by the two equations describing the consolidated government budget constraint at date 1 in the two states of the world:

$$\frac{(1+i_0)v_0 + b_0 - b_0^c}{p_1'} + \beta(B_0 - B_0^c) = \frac{\bar{f} - g + s}{1-\beta} - \phi, \tag{13}$$

$$\frac{(1+i_0)v_0 + b_0 - b_0^c}{p_1''} + \beta(B_0 - B_0^c) = \frac{\bar{f} - g + s}{1-\beta}. \tag{14}$$

The price level at date 1 does not affect the real value of the long-term bonds, because these bonds will come due at date 2, when the price level will be back on its target.

It follows right away that $p_1' > p_1''$. Prices rise if there is a crisis. Intuitively, if fiscal capacity falls, the government is no longer able to pay its debt. Surprise inflation is the only way to lower the debt's nominal value, so prices must rise in that state of the world relative to the alternative.

It also follows from these two equations that a form of QE that issues reserves to buy short-term government bonds will have no effect on the price level. Since, by arbitrage, $1 + i_0 = 1/q_0$, these purchases leave the left-hand side of the two equations unchanged. They exchange one short-term government liability for another, and Wallace neutrality applies.

If the purchases are of long-term government bonds, the picture changes. Since I just found that QE in the form of short-term bonds is neutral, let QE take place solely for buying long-term bonds: $\hat{v}_0 = Q_0 \hat{B}_0^c$. Then, subtracting the budget constraints at date 1 for these two states of the world reveals that:

$$\hat{v}_0 \left[\frac{1}{p''_1} - \frac{1}{p'_1} \right] = q_0 \phi. \tag{15}$$

The larger is the balance sheet of the central bank, the smaller is the dispersion of inflation across the two states of the world. The composition of QE is crucial: only when the central bank issues reserves to buy long-term bonds does it lower the dispersion of prices.

6.1 QE and expected prices

If instead of subtracting the budget constraints at the two states in period 1, one multiplies them by their probabilities and adds them, the result is:

$$[(1+i+0)v_0 + b_0 - b_0^c]\, \mathbb{E}_0 \left(\frac{1}{p_1} \right) + \beta(B_0 - B_0^c) = \frac{\bar{f} - g + s}{1-\beta} - \phi(1-\pi). \tag{16}$$

The deeper and more likely the crisis, the larger has to be the increase in expected prices. However, the increase in $\mathbb{E}_0(1/p_1)$ is independent of QE.[11]

Turning then to the date 0 version of equation (11), it is:

$$\frac{\frac{v_{-1}}{\beta} + b_{-1} - b_{-1}^c}{p_0} + \beta(B_{-1} - B_{-1}^c)\, \mathbb{E}_0 \left(\frac{1}{p_1} \right) = \frac{\bar{f} - g + s}{1-\beta} - \beta\phi(1-\pi). \tag{17}$$

The prospect of a crisis next period raises prices at date 0, relative to when no crisis is foreseen ($\pi = 1$). Yet, since $\mathbb{E}_0(1/p_1)$ is independent of QE, so is p_0. The central bank's policies at date 0 will not affect the price level then. All they do is affect the price level next period, but only in its sensitivity to the fiscal shock occurring.

6.2 QE and interest-rate policy

The previous results assumed that the central bank set interest rates to stick to its price-level target as long as it could. Therefore, while the price level might jump to p'_1 if the fiscal crisis materializes, prices return to 1 right away the next period. This way the central bank ensured that from period 2 onwards, uncertainty on prices was eliminated so the welfare costs of inflation Δ_t would be zero for all t from 2 onwards.

[11] Because the inverse function is convex, then larger QE that lowers the dispersion of prices will lower expected inflation.

Imagine that instead the central bank chose to let uncertainty and its welfare costs propagate for one more period. Concretely, let p_2 deviate from the target by equalling some multiple of the price level at date 1, which depending on the state of the world might have been p_1' or p_1''. The central bank can achieve this new target for p_2 by choosing interest rates at date 1 so that: $1 + i_1 = (1/\beta)(p_2/p_1)$.

The consolidated liabilities of the government at date 1 become:

$$\frac{(1+i_0)v_0 + b_0 - b_0^c}{p_1} + \frac{\beta(B_0 - B_0^c)}{p_2}. \tag{18}$$

Consider again the quantitative easing policy of issuing reserves to buy long-term bonds. Then, if $p_2 < p_1$, this policy would lower the dispersion of inflation, just as in the case where $p_2 = 1$ considered before. Alternatively, if $p_2 > p_1$, extending quantitative easing would magnify price dispersion, and if $p_2 = p_1$ neutrality would be restored.

This shows that it is the *joint* choice of QE and nominal interest rates that pins down the path of the price level after a fiscal crisis. Inflation is inevitable and has a fiscal source, but how inflation and its costs are smoothed over time depends on the central bank alone in the use of its tools, which must include QE.[12]

6.3 Intuition and desirability of QE

Collecting all of the results in this section: (i) the price level deviates from target in period 1, rising if there is a fiscal crisis, (ii) QE at date 0 using long-term bonds affects the dispersion of inflation during the crisis, (iii) the joint choice of QE and nominal interest rates determines the time-path of the price level from date 1 onwards.

Why is QE at date 0 not neutral on inflation at date 1? A fiscal crisis is a time when, unable to raise surpluses and unwilling to default, the only path for the fiscal authority it to erode of the the real value of the nominal debt payments coming due via inflation. The maturity of the public debt held by private agents is the key determinant of by how much surprise inflation lower the real value of the debt (Hilscher, Raviv, and Reis, 2014a). When the central bank buys long-term bonds, it shortens the maturity of the debt held by the public, so it makes more of the debt coming due. Thus, a smaller price increase is necessary to bring the real value of the outstanding debt in line with projected fiscal surpluses. While fiscal policy determines that inflation must happen, monetary policy can affect its time profile via QE.

[12]McMahon, Peiris, and Polemarchakis (2015) develop related points.

Both the fiscal crisis and QE affect unexpected inflation during the crisis. Therefore, a fiscal crisis comes with welfare losses both because of the costs of inflation, as well as because it leads to an output gap via aggregate demand. Since, without default, capital markets function efficiently, one is in the $k_t = 1$ case of the welfare lemma, and policy should focus on minimizing price surprises in order to keep output closer to its efficient level and minimize the misallocation due to inflation. According to the model, the central bank should then engage in QE by issuing reserves and buying long-term bonds. This will bring on price stability and reduce the output gap.

7 QE, default and credit freezes

The previous section assumed that the fiscal authority stayed committed to never defaulting. This section takes the other extreme case, where prices stay on target, so $p_t = 1$ at all dates, but the government defaults on its bonds after the crisis. I start by characterizing the impact of QE on default, and then proceed to analyze its effects on credit and welfare.

7.1 QE and the size of default

In period 1, there may or may not be a crisis. If there is no crisis, the government would neither like to default that period, nor have too little debt, since this would imply a larger default the previous period. Therefore, the government liabilities coming due in period 1 are pinned down by:

$$v_0/q_0 + b_0 - b_0^c + \beta(B_0 - B_0^c)] = \frac{\bar{f} - g + s}{1 - \beta}. \tag{19}$$

If instead there is a crisis, the same equation for the other state of the world pins down the extent of default in that state of the world:

$$\delta_1 = 1 - \frac{\phi}{\frac{\bar{f}-g+s}{(1-\beta)} - \frac{v_0}{\beta}}. \tag{20}$$

The higher is the fiscal loss, the larger the extent of default.

QE lowers the recovery rate in period 1, and this is the case whether it comes with buying short-term or long-term government bonds. Since central banks do not default on reserves, but fiscal authorities do, substituting one for the other will affect how much default per bond must happen to bring the fiscal situation into balance. More interesting, while QE changes the recovery rates on debt, the size of the transfer from bondholders to the government does not change. The extent of default in real terms is the same but, since there are fewer government bonds in private hands, each must pay back less to its holder. Therefore, QE provides no fiscal relief.

Finally, turning to period 0, the extent of default is:

$$\delta_0 = \min\left\{\frac{\frac{\bar{f}-g+s}{1-\beta} - \beta(1-\pi)\phi}{v_{-1}/\beta + b_{-1} - b^c_{-1} + \beta[\pi + (1-\pi)\delta_1](B_{-1} - B^c_{-1})}, 1\right\}. \tag{21}$$

QE only affects this quantity through the recovery rate at date 1. Intuitively, QE affects the recovery rate on bonds held in period 1, which affects their price at date 0. If the fiscal crisis was unexpected ($\pi = 1$), then there would be no default at date 0, nor any effect of QE at this date. More generally, the more unlikely the fiscal crisis, the less likely that there will be any default at date 0. Whereas default at date 1 depends on the size of the crisis, default at date 0 depends on the expectation that there will be a crisis in the future.

To conclude, QE can alter the size of the default per bond, but not its total size. It does not alter the flow of resources that default generates from the private to the public sector.

7.2 QE and ex post bank losses

In this subsection, I consider the case where $\pi \to 1$, so that default only happens at at date 1 and is completely unexpected. The next subsection will focus on the effects of $\pi < 1$.

Unexpected default hurts banks because they held government bonds b^p_0 as collateral in the interbank market. When they repay these loans in period 1, they suffer a loss of $b^p_0(1-\delta_1)$, a transfer from the banking sector to the fiscal authority. This loss lowers the net worth of banks so the incentive constraint in the deposit market in equation (4) tightens. Since banks have less skin in the game, they cannot raise as many deposits.

Combining these two effects, the amount of working capital invested in the economy is:

$$k_1 = \min\left\{\omega\kappa + x_1 + \left(\frac{\gamma(1+r)}{1-\gamma(1+r)}\right)[\omega\kappa - b^p_0(1-\delta_1)], 1\right\}. \tag{22}$$

If the repayment rate in period 1 is low enough that $k_1 < 1$ then, after a default, the higher are the bond holdings of the banks, the lower is the working capital invested.

QE can affect this amount. In the model, bonds are only held by banks across periods in order for the interbank market to work. But because bonds and reserves are perfect substitutes as forms of collateral, and only the good banks hold reserves, then when the supply of reserves increases, the bond holdings by banks decline. Therefore, higher v_0 lowers b_0^p one to one, and therefore raises investment, output, and welfare. This effect of QE happens regardless of whether QE is executed by buying short-term or long-term government bonds. Only the size of the central bank's balance sheet matters, and the larger it is, the lower the losses by banks.

7.3 QE and ex ante freezes due to default

Consider now what happens when $\pi < 1$. While in the previous subsection, the binding constraint on lending worked through the deposit market, the focus now is on the interbank market, where loans are constrained by:

$$x_1 \leq \left(\frac{1}{1-\xi}\right)[(\pi + (1-\pi)\delta_1)\beta b_0^p + v_0]. \tag{23}$$

The higher is ϕ, the lower is δ_1 from equation (20) and the lower the right-hand side as well. The lower is π, the lower the right-hand side. That is, both a larger and more likely fiscal crisis increase the risk premium on government bonds and make it more likely that this constraint binds. In that case, interbank lending is lower than the amount of working capital in the hands of unproductive banks, and there is too little investment, output and welfare.

To relax this constraint, banks would have to buy more bonds b_0^p to pledge as collateral. Through the mechanism discussed in the previous subsection, ex post losses will be larger as a result. At the same time, the amount of bonds that banks can hold is bound above by the supply of government bonds: $b_0^p \leq b_0$. If this constraint binds, there are not enough safe assets to serve as the collateral needed to sustain the functioning of the financial system, and the credit market freezes.[13]

QE can make up for the shortfall. While issuing reserves to buy short-term bonds would make no difference, QE that buys long-term bonds relaxes the constraint. More reserves allow for more financial transactions to take place between financial intermediaries, which in turn allows more investment to be allocated to those that have good opportunities. This

[13] Gorton (2010) and Caballero and Farhi (2016) argue that this was the case in 2008 as a result of the financial crisis, since increases in uncertainty led to rises in margins. In the model, this would map into ξ being lower in a financial crisis, which makes it more likely that equation (23) binds. Changes in financial regulation that would down weight risky government bonds would have a similar effect.

boosts credit, investment, output and welfare.[14]

8 What is special about reserves?

Bank reserves at the central bank have four crucial features that make them special:

1. Reserves are held exclusively by banks, as only they can hold these deposits at the central bank.

2. Reserves are supplied exclusively by the central bank, so it can freely set what interest to pay on them.

3. Reserves are default free, since the central bank can retire them at will or exchange them one to one at any time with fiat currency.

4. Reserves are the unit of account in the economy, so their nominal value never changes.

It is these four properties that give QE its effectiveness through the two channels that I explained. Because the central bank can issue reserves and set the nominal interest rate, it can affect the maturity of government liabilities held by the public while controlling expected inflation. This is what allows it to affect the extent of inflation surprises and aggregate demand during a fiscal crisis. Likewise, it is because the central bank can make sure that its reserves will be held by the banking system and that default does not affect their value, then the central bank can use QE to affect credit in the economy.

It is also these four properties that distinguish QE from either debt management or monetary financing of fiscal deficits, as I show next.[15]

8.1 QE versus Treasury debt management

A common criticism of QE policies is that their sole effect is to change the time profile of the overall government's obligations towards the public. Since the Treasury could do this itself, by changing the maturity of its bond issuances, QE would be unnecessary. Greenwood, Hanson, Rudolph, and Summers (2015) document that when the Federal Reserve extended the

[14] Benigno and Nistico (2013) provide a different model where QE again fills for a shortage of safe assets.

[15] It should also be obvious that macro prudential regulation is not a substitute for the roles played by QE in the model.

maturity of its bond portfolio after 2008, the U.S. Treasury increased the average maturity of the stock of public debt partly offsetting QE.[16]

In terms of the model in this paper, the fiscal authority chooses $\{b_t, B_t\}$. The question is whether this choice allows the Treasury to achieve the same outcomes as the central bank choosing $\{i_t, v_t, b_t^c, B_t^b\}$ regardless of what the central bank does. The answer is no:

Proposition 4. *Given an equilibrium for output, investment and inflation achieved by a QE policy, a debt-management policy that chooses* $\{b_t, B_t\}$ *cannot replicate this equilibrium, independently of monetary policy.*

This result can be broken into two complementary parts, as in the previous sections. First, consider the no-default case, to focus on the effect of the fiscal crisis on inflation, as done in section 6, and only then in second place, consider the effect of the fiscal crisis and QE on credit markets, as done in section 7.

With no default, the Treasury's choices of debt issuance could substitute for the QE policies of the central bank. Fearing a fiscal crisis, in period 0, the fiscal authority could change the relative issuance of short-term and long-term bonds to affect price dispersion and inflation. Yet, this cannot be achieved regardless of the central bank. The monetary authority must set an interest rate consistent with the debt issuance policy to achieve this path for inflation. Otherwise, as shown in Section 6.2, the fiscal policy could lead to more, less, or no effect on inflation. Expected inflation is pinned down by the nominal interest rate, while debt issuance determines how much of the fiscal crisis transmits into higher unexpected inflation. Only by coordinating these two policies can the effects of QE be attained.

Turning to credit markets, QE is again distinct from debt management. Even though reserves and short-term bonds can both be used as collateral, they are different in three key ways that determine their effectiveness. The first is that reserves are default free, unlike government bonds. If the government increases the supply of bonds, the recovery rate per bond will fall, but the overall loss to the private sector stays the same. By issuing reserves, the central bank gives banks a tool with which to shield their net worth, and so credit, from default. Bonds offer no such shield.

Second, reserves have to be held by banks, whereas bonds are held by banks and households. Therefore, when the monetary authority increases the supply of reserves, it is sure that these will be held by banks, lowering their exposure to default risk and reducing the

[16] In the opposite direction, Cochrane (2014) discusses monetary policy and QE as if it controlled perfectly the entire maturity structure of the debt outstanding, so that it becomes synonymous with Treasury debt management.

fall in net worth and credit after a fiscal shock. Instead, if the fiscal authority increases the supply of short-term government bonds, this simply leads to more holdings by the households, with no effect on credit or output. As long as there are enough bonds available, the household is the marginal holder of government bonds so changes in bond supply have no effect on banks.

The third property of reserves is that they are the unit of account, the nominal price of reserves is always 1 in nominal units. The price of bonds instead falls with an increase in the risk premium due to default. Therefore, as the fiscal crisis becomes more severe, for a given face value of bonds outstanding, their market value contracts, and their usefulness as a collateral diminishes, as I discussed in section 7.3. The ability of reserves to be used as a safe asset, on the other hand, is always constant by definition.

To be clear, this result does not imply its converse, that monetary policy can choose whatever outcome independently of fiscal policy. For instance, if the fiscal authority responds to QE by changing its debt choices, this will offset some of the effects of QE and may even make the joint policies counter-productive. As always, it is the coordination of fiscal and monetary policy that jointly determines macroeconomic outcomes and QE policies actually make this interdependence more visible. But, the special properties of reserves and the central bank's control of the nominal interest rate imply that QE and debt management are not the same policy.

8.2 QE and monetary financing of the debt

Another common criticism of QE is that a central bank that buys government bonds during a fiscal crisis must be engaging in monetary financing of the deficit. This argument was made particularly forcefully during the implementation of QE by the ECB during the euro-crisis.

In terms of the model, the answer is again clear: QE does not generate any extra resources for the fiscal authority, independently of consumption and output in the economy. This can be easily seen from the consolidated intertemporal budget constraint of the government in equation (11). The central bank only generates fiscal revenues insofar as it increases the present value of seignorage. But, seignorage is exogenous in the model. Therefore, there is no transfer of resources to the fiscal authority across all the policy experiments in this paper so far.

A related accusation of QE is that it prevents sovereign default and/or is inflationary. Yet, as emphasized in section 7, QE actually reduces the recovery rate on government bonds in a fiscal crisis. The transfer of resources from the private to the public sector during a default was exactly the same irrespective of QE. By taking bonds away from private hands, the central bank rather makes the default on each bond be more intense. Moreover, in that section inflation was kept at zero throughout and, in section 6, QE could not affect the expected inverse of inflation. QE was not inflationary.

QE is not monetary financing because it does not involve money but rather interest-paying reserves. To understand this difference, consider a simple extension of the model, where the central bank issues a second liability, currency, denoted by h_t, which pays no interest. Households hold currency because it provides some services captured by an additive term in the utility function, while banks can choose to hold it as another source of seizable in the interbank market. Seignorage is now endogenous: $s_t = (h_t - h_{t-1})/p_t$.

All of the results in the baseline model still apply to this extension as long as the central bank chooses the supply of currency to accommodate the demand for it by households in a way that is consistent with its interest-rate policy and price-level target. No modern central bank uses the supply of currency as its operating tool, so this is realistic and all of the effects of QE remain.

Consider however an alternative policy to QE, whereby the central bank issues currency to buy government bonds. In this case:

Proposition 5. *Given an equilibrium for output, investment and inflation achieved by a QE policy, a monetary-financing policy that uses h_t to buy $q_t b_t^c + Q_t B_t^c$ cannot replicate this equilibrium.*

Monetary purchases of long-term government bonds change the maturity of government liabilities held by the public and affect the extent of surprise inflation. Moreover, currency provides a safe asset that the financial market can use to operate in a fiscal crisis.

However, monetary financing comes with three important differences relative to QE. First, currency is not exclusively held by banks, unlike reserves. Therefore, as with the issuance of more short-term government bonds, issuing currency will not prevent the credit crunch that comes with the fall in bank net worth after a default, since it is the household, not banks, that holds currency at the margin.

Second, issuing currency as an independent policy tool comes with inflation. Given a money demand function an exogenous increase in h_t comes with an increase in the price level which, if unexpected, lowers welfare in the model.

Third, issuing currency will increase seignorage, s_t. Unlike reserves, which pay interest, currency does not remunerate its holder, so that when the central bank borrows using currency and invests in interest-earning assets it earns a revenue. As this is transferred to the fiscal authorities, it constitutes proper monetary financing of the deficits.

There is therefore some truth to the claim that purchases of government bonds by the central bank can come with higher inflation and monetary financing of the deficit. But this only happens if these purchases are financed with issuing currency. QE uses instead interest-paying reserves.[17]

8.3 Other reasons and criticisms of QE

One common argument for QE is that it may stimulate the economy when interest rates are zero. This is consistent with the analysis in this paper, since a variant of this model has been used to study the effectiveness of policy at the zero lower bound (Eggertsson and Woodford, 2003). Yet, the two mechanisms that I have identified are independent of the value of the nominal interest rate. This is easily seen in the model by replacing the price level target with one that has an arbitrary deterministic target value for inflation: $p_t = \bar{p}_t$. The only change in the model is to the nominal interest rate rule in order to achieve this target. The effectiveness of QE is completely unchanged.

More relevant is whether the real interest rate r_t is positive. So far, I have always assumed it is so. If not, then agents in the economy are better off consuming the working capital rather than using it for production. In this case, QE is neutral as is any other policy that tries to stimulate credit. Banks will not lend any resources out, as investment is not profitable.

Another argument for QE is that it may overcome limits to arbitrage, or liquidity problems, in the bond market. In the model above, arbitrage held across asset classes in equation (6) without any liquidity problems. Even more starkly, in all the cases considered, the expectations hypothesis of the term structure held at date 0:

$$\frac{1}{Q_0} = \frac{1}{q_0\,\mathbb{E}_0(q_1)}. \tag{24}$$

Yet, QE was still effective, even though there was no risk premium.

Finally, one might argue that QE allows fiscal authorities to not implement needed reforms. This was possible in the model, since the fiscal authority could choose any $f_t \leq \bar{f}_t$. Yet, it was not optimal as the fiscal authorities optimally chose the maximum taxation at all dates after a crisis, $f_t = \bar{f}_t$. This was true whether QE was present or not. A fiscal crisis

[17] Required reserves, that pay below-market interest, have effects closer to currency than to the voluntarily-held bank reserves considered in this paper.

is socially costly, and if the fiscal authorities can reduce its size, it will be optimal to do so.

Related, consider an extension of the model where the fiscal authority can choose g_t, the government purchases that so far I have assumed were exogenous. In that case, by cutting spending, the fiscal crisis could be averted. That is, at date 0, learning of the fall in its fiscal capacity, the government could lower g_t in the present or future and prevent default next period. This unexpected cut in g_t would cause a recession by lowering aggregate demand. It is possible that this policy may be better or worse than QE at dealing with the fiscal crisis. Yet, as long as cuts in spending do not fully address the fiscal crisis and put the economy back in normal times, then QE will still be effective through the channels discussed above.

9 Limitations of QE

So far, this paper has established that QE can have an effect on macroeconomic outcomes in a fiscal crisis, and it can raise welfare. Even within the model though, there are limitations to what QE can achieve that can prevent policy from achieving the first best.[18]

9.1 Central bank solvency

By issuing reserves to buy long-term bonds, the central bank is engaging in maturity transformation, and with it comes risk. When default or inflation lead to a capital loss in the holding of these bonds, the central bank will make losses. Engaging in QE increases these potential losses.

If the central bank enjoys unlimited fiscal backing from the Treasury, these losses are irrelevant for equilibrium. As shown by Hall and Reis (2015b), as long as the central bank pays dividends equal to net income every period, which includes potentially receiving payments from the fiscal authority if net income is negative, then it can implement QE while always staying solvent. QE may lower the present value of dividends that the central bank can distribute to the fiscal authority but, from the perspective of the consolidated budget of the government, this is immaterial since the losses of the central bank are the gains of the fiscal authority.

In a fiscal crisis, though, the fiscal authority may not be willing to provide this fiscal backing to the central bank. The historical experience rather suggests the opposite: during a fiscal crisis, the Treasury tries to extract more resources from the central bank (Sargent,

[18]An obvious limitation is that there must be enough long-term government bonds outstanding for the central bank to buy so the constraints $b_t \geq b_t^c \geq 0$ do not bind and likewise for B_t^c.

1982). This places a solvency constraint in the central bank's actions, in the form of a lower bound on the (possibly negative) dividends to the fiscal authorities. There are different possible types of insolvency for a central bank depending on the relationship between the central bank and the fiscal authority (Reis, 2015). They may rule out the optimal QE policy and limit the size of the QE operations.

9.2 QE comes with redistribution

When there is default, QE involves redistribution of resources within society. As discussed in section 7, on the one hand, banks holding reserves can lower their losses after government default. On the other hand, QE lowers the recovery rate of government bonds. Since QE kept unchanged the bonds being held by households, it follows that households have higher losses due to default.

These two effects exactly cancel out. The government budget constraint imposes that the private sector must lose precisely the same amount in order to bring the value of the outstanding debt back in line with the post-crisis present value of fiscal surpluses. QE lowers the losses of banks by increasing the losses of households. As banks are given access to an exclusive vehicle, reserves, that provides a shield from the costs of default, the non-bank holders of government bonds lose more in default.

In the model, this only improves welfare because there is no welfare cost of redistributing resources away from households coupled with a benefit from avoiding losses by banks. But, the model also abstracts from limitations to this redistribution or to other reasons for redistributing resources in the other direction.

9.3 QE targeting to increase the supply of safe assets

QE affects the net supply of safe assets in the economy only insofar as the extra reserves can buy risky assets. In the model, QE that bought long-term bonds relaxed the incentive constraint in the interbank market. But, if QE bought short-term bonds instead, then the supply of safe assets would be unchanged. This was driven by the assumptions that only short-term bonds and reserves showed up in that constraint.[19]

This assumption tightly linked safety to maturity. But all that matters is that the central bank can use QE to buy some assets that are risky, and not those that are as safe as reserves.

[19] Including long-term bonds in the incentive constraint of bankers in the interbank market would only make a difference to the results in the paper regarding the provision of safe assets and the ex ante freezes in the interbank market in a crisis.

As long as the demand for safe assets by banks exhaust all of the government bonds available that can fulfill this role, and that there are other assets that QE can buy so that it can on net create safe assets by issuing reserves, then QE would still be effective.

In reality, it may be hard to measure which assets are safe or not. In that case, many forms of QE may turn out to be ineffective, just as purchases of short-term bonds were in the model. Related, there may be a limit to QE if the supply of public debt at different maturities is too low.

9.4 QE in the open economy

The model in this paper was of a closed economy. Considering international capital markets would bring in further limitations to QE policies.

First, banks that partially fund themselves from abroad need collateral that foreigners find safe. Yet, reserves at a foreign central bank are not nominally safe from the domestic banking sector's perspective because of changes in the exchange rate. Since QE would lead to changes in the exchange rate, this might limit its effects. Moreover, by taking domestic bonds away from the bank's balance sheet, the central bank may increase the temptation for the government to default, raising the risk premium on foreign borrowing and lowering credit (Perez, 2015; Balloch, 2015).

Second, in the model in this paper, all government bonds were held domestically. Therefore, from the perspective of the national economy, there was no benefit in defaulting, and so government default only happened when it was inevitable. If some of the bonds were held abroad, then the government might voluntarily choose to default and in turn this would affect the interest paid on the public debt. QE would determine not only the total amount of government bonds outstanding, but also potentially how many are held abroad and their maturity, affecting the relative benefits and costs of sovereign default as well as the ability to commit to policies.

Third, with multiple regions, which government bonds the central bank buys could have differential effects on inflation and financial constraints in different regions. At the same time, QE could lead to redistribution across borders (Reis, 2013b).

10 Conclusion

This paper put forward arguments for why quantitative easing can be a tool for the future in central banking. The goal was to discuss new channels for QE to have an effect and to discuss the assumptions and mechanisms behind these channels. While QE may have been neutral in the past, in a future where fiscal crises are possible and perhaps long lasting, QE can play two roles. First, it can allow the central bank to stabilize inflation by managing the sensitivity of inflation to fiscal shocks. Second, it can prevent a credit crunch after a fiscal crisis by lowering the losses suffered by banks during a default and providing safe assets that financial markets can use to promote financial stability. Each of these roles is consistent with the traditional objectives of central banking: stabilizing inflation, real activity and financial activity. This paper described how managing the size and composition of the central bank's balance sheet could exploit these channels to achieve better outcomes.

The perspective of the paper was of looking into the future. The model purposely ruled out the reasons why QE may have been effective during the recent period of financial crisis and zero interest rates. An assessment of what should be the optimal size of a central bank's balance sheet today, or of whether the QE policies from the crisis should be unwound, would require merging the arguments in this paper with those in the rest of literature. This was not the goal of this paper, but it should be high on the list for future research.

In spite of this future perspective, the arguments in this paper can be used to reassess past policies. Two examples come from the ECB's recent experience. First, starting in 2010, the ECB announced it would purchase sovereign bonds held by banks as part of its SMP, which was then modified into the OMT. The goal was to remove risky assets from banks in order to spur credit. Initially, the purchases were sterilized, so they came with no increase in reserves. Unsatisfied with the effectiveness of of the program to spur credit, the ECB stopped sterilizing these interventions in 2014. The model in this paper predicts that stopping the sterilization would have made these purchases effective.

Second, starting in 2009, the ECB greatly increased the supply of reserves, in large part through its LTRO program. The logic used to justify this was similar to the model of the interbank market in this paper, as it was perceived that banks needed safe assets for collateral so that the financial market could function. Yet, there is little evidence that the program led to an increase in credit. The model would predict this if the incentive constraint was not binding, and provides some support to the more recent targeted LTRO program that requires banks to increase credit in exchange for the reserves.

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Appendix

A Formal statement of the model and equilibrium

This section collects all of the pieces of the model presented in the paper, starting with the decision problems of the agents, moving to the market clearing conditions, and ending with the definition of equilibrium.

Households: The representative household chooses $\{c_t, l_t, b_t^h, B_t^h, z_t\}$ to maximize the utility function in equation (5) subject to the budget constraint:

$$p_t c_t + q_t b_t^h + Q_t B_t^h + p_t z_t = w_t l_t + \delta_t (b_{t-1}^h + q_t B_{t-1}^h) + R_t^z p_t z_t + p_t (1-\kappa) - p_t \tilde{f}_t \tag{A1}$$

at all dates t, and a standard no Ponzi scheme condition. The bond holdings by households are denoted by (b_t^h, B_t^h). While in principle the household can issue bonds similar to government bonds (but which could not be used as collateral by banks), the market clearing condition that these private bonds are in zero net supply is already incorporated into the notation. Deposits earn a real return R_t^z and are subject to a no short-selling constraint as well as the fact that only working capital is deposited $0 \leq z_t \leq 1-\kappa$. Moreover, the household will take into account the incentive constraint of the banks in determining how much to deposit. Finally, $\tilde{f}_t$ are the net taxes paid by the household.

The sufficient and necessary optimality conditions for this dynamic problem are the Euler equations with respect to the two bonds in equations (6), the labor supply condition:

$$l_t^\alpha = w_t / p_t, \tag{A2}$$

where w_t is the nominal wage rate, the budget constraint above holding with equality together with a transversality condition defining its intertemporal counterpart, and finally the condition that if $R_t^z \geq 1$ then z_t will be the minimum of $1-\kappa$ or the value at which the bank's incentive compatibility constraint binds.

Competitive final goods firms: They maximize equation (7) every period subject to the budget constraint that total spending E_t is equal to $E_t = \int_0^{k_t} p_t(j) y_t(j) dj$. Standard derivations reveal that the solution to this problem is:

$$y_t(j) = \left(\frac{p_t(j)}{p_t}\right)^{-\sigma} k_t^{\theta\sigma} y_t, \tag{A3}$$

$$p_t = \left[k_t^{\theta\sigma} \int_0^{k_t} p_t(j)^{1-\sigma} dj\right]^{1/(1-\sigma)}, \tag{A4}$$

where p_t is the static cost-of-living price index with the property that $E_t = p_t y_t$.

Intermediate goods firms: A firm j that can change its price with full information this period will choose $\{y_t(j), l_t(j), p_t(j), k_t(j)\}$ to maximize profits:

$$X_t = \frac{1}{p_t}\left[\left(\frac{\sigma}{\sigma-1}\right) p_t(j) y_t(j) - w_t l_t(j) - p_t(1+r_t) k_t(j)\right] \tag{A5}$$

subject to: the demand for the good in equation (A3), the production technology $y_t(j) = a_t l_t(j)$, and the set up cost of working capital $k_t \in \{0, 1\}$. $\sigma/(\sigma - 1)$ is a standard sales subsidy to offset the monopoly distortion.

Simple algebra shows that the firm will choose the optimal nominal price:

$$p_t^* = \frac{w_t}{a_t}. \tag{A6}$$

In turn the zero profit condition, $X_t = 0$ from free entry (subject to $k_t \leq 1$) implies that if a firm is in operation ($k_t(j) = 1$) then:

$$1 + r_t = \left(\frac{1}{\sigma - 1}\right)\left(\frac{w_t l_t(j)}{p_t}\right). \tag{A7}$$

Turning to the uninformed firms, their problem is similar but now they maximize expected profits discounting uncertainty using the household's stochastic discount factor so:

$$p_t^{*e} = \arg\max_{p_t(j)} \mathbb{E}_{t-1}\left(m_{t-1,t} X_t\right) = \frac{\mathbb{E}_{t-1}\left(\frac{w_t k_t^{\theta\sigma} y_t}{a_t p_t^{1-\sigma}}\right)}{\mathbb{E}_{t-1}\left(\frac{k_t^{\theta\sigma} y_t}{p_t^{1-\sigma}}\right)}. \tag{A8}$$

A log-linearization around the certainty case would give the familiar result: $p_t^{*e} = \mathbb{E}_{t-1}(p_t^*)$.

Finally, to derive equation (9), first note that integrating the production function over all firms gives: $\int y_t(j) dj = a_t l_t$. Next, recalling that there are only two types of firms and that the demand of their good is given in equation (A3), gives:

$$\int y_t(j)dj = k_t \left[\lambda \left(\frac{p_t^*}{p_t} \right)^{-\sigma} k_t^{\theta\sigma} y_t + (1-\lambda) \left(\frac{p_t^{*e}}{p_t} \right)^{-\sigma} k_t^{\theta\sigma} y_t \right]. \tag{A9}$$

Rearranging delivers the expression for Δ_t.

Unproductive banks: A bank at date $t-1$ receives its ownership claim on period t capital. At that date, the bank faces the following resource constraint:

$$p_{t-1}x_t + \tilde{v}_{t-1} + q_{t-1}\tilde{b}_{t-1}^p + Q_{t-1}\tilde{B}_{t-1}^p + p_{t-1}q_{t-1}^x \tilde{x}_t \leq p_{t-1}q_{t-1}^x(1-\omega)\kappa. \tag{A10}$$

That is, the unproductive bank can lend to good banks x_t, to the central bank $\tilde{v}_{t-1}$, to the fiscal authority $(\tilde{b}_{t-1}^p, \tilde{B}_{t-1}^p)$, or keep its capital claims to itself $\tilde{x}_t$ where their shadow price is q_{t-1}^x. The banks makes these decisions to maximize the profits they will have next period:

$$\max \mathbb{E}_{t-1} \left(\frac{m_{t-1,t}}{p_t} \right) \left[(1+R_{t-1}^x)x_t + (1+i_{t-1})\tilde{v}_{t-1} + \delta_t(\tilde{b}_{t-1}^p + q_t\tilde{B}_{t-1}^p) + p_t\tilde{x}_t \right] \tag{A11}$$

and subject to an upper bound on x_t in order to maintain incentives for repayment. R_{t-1}^x is the promised repayment on the interbank market, while capital tomorrow can only be turned into consumption and sent into that form to the household. At date t an unproductive bank can no longer sell its capital to good banks or send it to households, but only convert it into consumption.

Optimal behavior by the unproductive banks implies that for there to be a solution with non-infinite holdings of each asset, the arbitrage conditions in equations (6) hold as well as:

$$(1+i_t)\,\mathbb{E}_t \left(\frac{m_{t,t+1}p_t}{p_{t+1}} \right) = 1, \tag{A12}$$

$$i_t = R_t^x. \tag{A13}$$

Because the bad banks are indifferent between the use of all these funds, the amount invested in each is indeterminate. Again, I break this indeterminacy by assuming that the bank lends in the interbank market all of its capital, or that x_t is driven to its incentive upper bound.

Productive banks: These banks make three choices on: lending, deposit-taking, and interbank borrowing. I discuss each in turn, moving backwards in time.

At date t, having collected the capital from deposits and interbank loans, the bank chooses whether to lend those resources to the firms, or to turn them into consumption. As long as the interest rate on those loans r_t is larger than zero, the bank will lend the capital out. Assumption 2 ensures this is the case when prices are flexible, and in all other cases in the paper I always verify that the condition holds. Therefore:

$$k_t = \omega\kappa + x_t + z_t \leq 1. \tag{A14}$$

Moving one step backwards in time, the banks enter period t with bond and reserve holdings, as well as debts in the interbank market. Their available capital at this stage is $\omega\kappa + x_t$, after they sell their collateral, which no longer serves any useful role. The productive banks owe x_t to the unproductive banks, and the incentive constraint and the seniority of interbank debt ensure that this debt is repaid in full. Therefore, it is the good bank that suffers the loss when this collateral does not pay in full. Therefore, the bank's net worth after settling claims in the interbank market and selling its collateral is:

$$n_t = \omega\kappa - b^p_{t-1}(1 - \delta_t). \tag{A15}$$

The banks then go to the deposit market to collect capital from households. Since they will earn a return $1 + r_t > 1$ on capital and only pay $R^z_t = 1$ to deposit holders, they would like to collect as much as possible. However the incentive constraint in equation (4) puts an upper bound on how much the banks can collect in this market. Combining it with the expression for net worth above gives:

$$z_t \leq \left(\frac{\gamma(1+r)}{1-\gamma(1+r)}\right)[\omega\kappa - b^p_{t-1}(1 - \delta_t)]. \tag{A16}$$

Finally, consider the choices at period $t - 1$. The productive banks, owning claims on $\omega\kappa$ of capital can sell them to buy different financial assets just like the unproductive banks. However, next period, these banks would then not have the capital that earns higher returns r_t. Therefore, they will never wish to do so (recall that only households can sell capital to banks in period t, through deposits) unless it relaxes another constraint. That constraint is the incentive constraint in the interbank market in equation (4). Since banks must hold reserves, it then follows that this incentive constraint will always bind and that the banks' demand for bonds, after rearranging equation (3) is:

$$b_{t-1}^{p}=\frac{(1-\xi)x_t-v_{t-1}}{q_{t-1}}\leq b_{t-1} \tag{A17}$$

where the last inequality reflects the market constraint that banks cannot hold more government bonds than the ones that there are.

As for the amount of interbank lending, x_t, I have already determined that by paying an interest rate an epsilon above the market interest rate, then the unproductive banks would like to lend out all of its $(1-\omega)\kappa$ claims on capital. Then, there are two cases: either the bond holdings of productive banks are strictly below the amount of bonds outstanding, so

$$x_t=(1-\omega)\kappa, \tag{A18}$$

$$b_{t-1}^{p}=\frac{(1-\xi)(1-\omega)\kappa-v_{t-1}}{q_{t-1}}\leq b_{t-1}, \tag{A19}$$

or instead the constraint on the total amount of bonds available binds and:

$$x_t=\frac{q_{t-1}b_{t-1}+v_{t-1}}{1-\xi}, \tag{A20}$$

$$b_{t-1}^{p}=b_{t-1}. \tag{A21}$$

Fiscal policy: The fiscal authorities choose $\{f_t,\delta_t,b_t,B_t\}$ subject to the flow budget constraint in equation (1). The no Ponzi scheme on government debt is $\lim_{T\to\infty}\mathbb{E}_t[\delta_{t+T}(b_{t+T-1}+q_{t+T}B_{t+T-1})/p_{t+T}]=0$, which, using the arbitrage conditions on different assets to iterate forward the flow budget constraint, can be written as the intertemporal budget constraint:

$$\left(\frac{\delta_t}{p_t}\right)(b_{t-1}+q_tB_{t-1})=\mathbb{E}_t\left[\sum_{\tau=0}^{\infty}m_{t,t+\tau}(d_{t+\tau}+f_{t+\tau}-g_{t+\tau})\right]. \tag{A22}$$

I take the choices of $\{b_t,B_t\}$ as given and consider different policy regimes for $\{\delta_t\}$. Therefore, the only choice for the government is to set $f_t\leq\bar{f}_t$. Since fiscal crises come with welfare costs, and these strictly decline with f_t, in a crisis the fiscal authority will always want to set f_t as high as possible. Note that:

$$f_t=\tilde{f}_t-\left(\frac{1}{\sigma-1}\right)\int p_t(j)y_t(j)dj. \tag{A23}$$

Central bank: The central bank chooses $\{i_t, v_t, b_t^c, B_t^c\}$ subject to the flow budget constraint in equation (2) and the intertemporal constraint that follows from the no-Ponzi scheme on reserves:

$$\frac{(1+i_{t-1})v_{t-1} - \delta_t(b_{t-1}^c + q_t B_{t-1}^c)}{p_t} = \mathbb{E}_t\left[\sum_{\tau=0}^{\infty} m_{t,t+\tau}(s_{t+\tau} - d_{t+\tau})\right]. \tag{A24}$$

I restrict the set of policies to study as quantitative easing, understood as changes in the balance sheet such that $\hat{v}_t = q_t \hat{b}_t^c + Q_t \hat{B}_t^c$, where hats denote changes. Interest rates are either chosen following a rule, like the Taylor rule, that enforces the price level target $p_t = 1$, or instead accommodate the real interest rates and inflation determined elsewhere in the model, given the Fisher equation (A13).

Market clearing: There is no storage technology or any way to transfer resources over time, so the market clearing condition for goods is:

$$c_t + g_t + k_t = y_t + 1. \tag{A25}$$

In the labor and capital market, clearing requires, respectively:

$$l_t = \int l_t(j)dj, \tag{A26}$$

$$k_t = \int k_t(j)dj. \tag{A27}$$

Market clearing in deposit, interbank and reserves is already implicit in the notation, while market clearing in the government bonds market requires:

$$b_t = b_t^c + b_t^p + \tilde{b}_t^p + b_t^h, \tag{A28}$$

$$B_t = B_t^c + \tilde{B}_t^p + B_t^h. \tag{A29}$$

Equilibrium: Repeated from the text, an equilibrium is a collection of outcomes in goods markets $\{c_t, y_t, y_t(j), p_t, p_t(j)\}$, in labor markets $\{l_t, l_t(j), w_t\}$, in the credit, deposit and interbank markets $\{r_t, k_t, x_t, z_t, b_t^p\}$, and in bond markets $\{q_t, Q_t\}$, such that all agents behave optimally and all markets clear, and given exogenous processes for $\{\bar{f}_t, s_t, a_t, g_t\}$ together with choices for fiscal policy $\{f_t, \delta_t, b_t, B_t\}$ and monetary policy $\{i_t, v_t, b_t^c, B_t^c\}$.

B Proof of Lemma 1: the welfare function

The first best of the economy is easy to describe since it solves:

$$\begin{aligned}
\max \mathbb{E}_t & \left[\sum_{\tau=0}^{\infty} \beta^{\tau} \left(c_{t+\tau} + g_{t+\tau} - \frac{l_{t+\tau}^{1+\alpha}}{1+\alpha}\right)\right] \\
y_t &= \left(k_t^{\theta} \int_0^{k_t} y_t(j)^{\frac{\sigma-1}{\sigma}} dj\right)^{\frac{\sigma}{\sigma-1}} \\
y_t(j) &= \begin{cases} a_t l_t(j) & \text{if } k_t(j) = 1 \\ 0 & \text{if } k_t(j) = 0 \end{cases} \\
l_t &= \int_0^{k_t} l_t(j) dj \\
k_t &= \int_0^{1} k_t(j) dj \\
c_t + g_t + k_t &= y_t + 1.
\end{aligned}$$

It is easy to see that the optimal solution requires symmetry so $l_t(j), y_t(j)$ are the same for all j and so $l_t = k_t l_t(j)$ and $y_t = k_t^{(1+\theta)\sigma/(\sigma-1)} y_t(j)$. Replacing these into the objective function, together with the resource constraint and the production function, gives a static optimization problem at every date t to choose k_t and l_t.

For that problem, as long as the two conditions in assumption 2 hold, then welfare is strictly increasing in capital in the $[0,1]$ interval. Therefore, $k_t(j)^* = k_t^* = 1$. Optimality with respect to l_t then implies that $l_t(j)^* = l_t^* = a_t^{1/\alpha}$ for all j, that $y_t(j)^* = y_t^* = a_t^{(1+\alpha)/\alpha}$ for all j, and that $c_t^* = y_t - g_t$.

One can then manipulate the utility function to obtain:

$$c_t + g_t - \frac{l_t^{1+\alpha}}{1+\alpha} = y_t + 1 - k_t - \frac{\left(\frac{y_t k_t^{\frac{1+\sigma\theta}{1-\sigma}} \Delta_t}{a_t}\right)^{1+\alpha}}{1+\alpha} \tag{A30}$$

$$= y_t + k_t^* - k_t - \frac{\left(y_t k_t^{\frac{1+\sigma\theta}{1-\sigma}} \Delta_t\right)^{1+\alpha}}{y_t^{*\alpha}(1+\alpha)} \tag{A31}$$

$$= y_t^* \left[\frac{y_t}{y_t^*} + \frac{k_t^* - k_t}{y_t^*} - k_t^{-\alpha} \left(\frac{y_t}{y_t^*}\right)^{1+\alpha} \frac{\Delta_t^{1+\alpha}}{1+\alpha}\right]. \tag{A32}$$

The first equality comes from using the market clearing condition for goods and the aggregate production function; the second equality from using the definition of (y_t^*, k_t^*), and the third from simple division and from assumption 2.2. This proves the lemma.

C Proof of proposition 2

From date 2 onwards there are no more shocks. Because there are no relevant dynamics, I drop the t subscript from all variables. I conjecture that $p_1 = \delta_1 = 1$ and verify that this is consistent with equilibrium.

All firms have full information, so they all choose the same output level $y(j)$ and the same prices, so there is no price dispersion $\Delta = 1$. The equilibrium conditions in the real side of the economy are:

$$y = k^{\frac{(1+\theta)\sigma}{\sigma-1}} y(j) \tag{A33}$$

$$al = ky(j) \tag{A34}$$

$$l^\alpha = w \tag{A35}$$

$$k^{\frac{1+\theta\sigma}{\sigma-1}} = \frac{w}{a} \tag{A36}$$

$$1 + r = \left(\frac{1}{\sigma - 1}\right) \frac{wy(j)}{a}. \tag{A37}$$

These 5 equations can be easily solved for the 5 unknown variables $(y(j), y, l, w, r)$ as a function of k.

From the solution for the real interest rate:

$$1 + r = \left(\frac{a^{1+1/\alpha}}{\sigma - 1}\right) k^{(1+1/\alpha)(1+\theta\sigma)/(\sigma-1)-1}. \tag{A38}$$

Assumption 2 implies that this expression is constant and that $r > 0$. Therefore, on the banker's side they will want to maximize k subject to their incentive constraints, which must therefore bind.

Turning to the capital market, combining all the equilibrium conditions gives:

$$k = \omega\kappa + x + z \tag{A39}$$

$$z = \min\left\{\left(\frac{\gamma(1+r)}{1-\gamma(1+r)}\right)(\omega\kappa), 1-\kappa\right\} \tag{A40}$$

$$x = \min\left\{(qb+v)/(1-\xi), (1-\omega)\kappa\right\} \tag{A41}$$

$$b^p = \min\left\{b, \frac{(1-\xi)x - v}{q}\right\}. \tag{A42}$$

The arbitrage conditions for bonds imply right away that:

$$q = (1+i)^{-1} = \beta, \tag{A43}$$

$$Q = \beta^2. \tag{A44}$$

Then, this set of conditions becomes simply: $k = 1, z = 1-\kappa, x = (1-\omega)\kappa$, as long as:

$$b \geq \frac{(1-\xi)(1-\omega)\kappa - v}{\beta}. \tag{A45}$$

Next turn to the intertemporal budget constraint of the government evaluated at the bond prices above. From date 2 onwards it must be that:

$$\frac{v_{t-1}}{\beta} + b_{t-1} - b^c_{t-1} + \beta(B_{t-1} - B^c_{t-1}) = \sum_{\tau=0}^{\infty} \beta^\tau f_{t+\tau} + \frac{s-g}{1-\beta}. \tag{A46}$$

Given a default or inflation at date 1, the debt brought forward will satisfy this condition. This concludes the proof: $p_t = \delta_t = 1$ satisfies all the equilibrium conditions from date 2 onwards.

D Proof of proposition 1

Proposition 1 is a corollary of proposition 2. With no fiscal crisis, all the steps in the proof can be restated for dates 0 and 1. Moreover, with the choice of f_t in the proposition, and the condition on b_t, then the two conditions stated in the proof of proposition 2 hold. Among all the equilibrium conditions, clearly the QE policy choices only appear in equation (A46), so that QE is neutral.

E Proof of proposition 3

Given δ_1, at date 0, the intertemporal budget constraint of the government at dates 0 and 1, after replacing arbitrage conditions, are:

$$\frac{v_{-1}/\beta + b_{-1} - b^c_{-1}}{p_0} + \beta(B_{-1} - B^c_{-1})\,\mathbb{E}_0\left(\frac{\delta_1}{p_1}\right) = \frac{\bar{f} - g + s}{1-\beta} - \beta\phi(1-\pi), \tag{A47}$$

$$\frac{v_0}{\beta p_0 p_1\,\mathbb{E}_0(1/p_1)} + \delta_1\left[\frac{(b_0 - b^c_0)}{p_1} + \beta(B_0 - B^c_0)\right] = \frac{\beta\bar{f} - g + s}{1-\beta} + f_1. \tag{A48}$$

Recall that there are two possible values of f_1 and so two of the last equation, determining two values of p_1, one for each state. Therefore, these are three equations pinning down three values p_0, p'_1, p''_1.

Turning to the capital markets at $t = 0, 1$, as studied in the previous section of the appendix, as long as $r_t > 0$, which I will verify in every case, then

$$k_t = \omega\kappa + x_t + z_t \tag{A49}$$

$$z_t = \min\left\{\left(\frac{\gamma(1+r_t)}{1-\gamma(1+r_t)}\right)[\omega\kappa - b^p_{t-1}(1-\delta_t)], 1-\kappa\right\} \tag{A50}$$

$$x_t = \min\left\{(q_{t-1}b_{t-1} + v_{t-1})/(1-\xi), (1-\omega)\kappa\right\} \tag{A51}$$

$$b^p_{t-1} = \min\left\{b_{t-1}, \frac{(1-\xi)x_t - v_{t-1}}{q_{t-1}}\right\}. \tag{A52}$$

At date 0, I assume that $k_0 = 1, z_0 = 1-\kappa, x_0 = (1-\omega)\kappa$. But at date 1, given the two states of the world, there are two possible values for k_1, z_1 and one for x_1, b^p_0, taking δ_1 as given from the previous block. Focusing on the case where the incentive constraints bind and all channels are operative, this system becomes:

$$k_1 = \omega\kappa + x_1 + z_1 \tag{A53}$$

$$z_1 = \left(\frac{\gamma(1+r_1)}{1-\gamma(1+r_1)}\right)[\omega\kappa - b^p_0(1-\delta_1)] \tag{A54}$$

$$x_1 = (q_0 b_0 + v_0)/(1-\xi) \tag{A55}$$

$$b^p_0 = b_0. \tag{A56}$$

Note that assuming that the first best is achieved at date 0, but at date 1 all constraints bind, puts restrictions on parameters $\gamma, \omega, \kappa, b^p_0$.

Given the k_1, p_0, p_1 pinned down this way, one can finally turn to the real side of the economy. Combining all equilibrium conditions, and dropping the time index notation for convenience of the notation, the equilibrium in the real side of the economy at $t = 0, 1$ is:

$$y = k^{\frac{(1+\theta)\sigma}{\sigma-1}} \left(\lambda {y^*}^{\frac{\sigma-1}{\sigma}} + (1-\lambda) {y^{*e}}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \tag{A57}$$

$$y^* = \left(\frac{p^*}{p} \right)^{-\sigma} k^{\theta\sigma} y \tag{A58}$$

$$y^{*e} = \left(\frac{p^{*e}}{p} \right)^{-\sigma} k^{\theta\sigma} y \tag{A59}$$

$$al = k \left(\lambda y^* + (1-\lambda) y^{*e} \right) \tag{A60}$$

$$\frac{w}{p} = l^\alpha \tag{A61}$$

$$p^* = w/a \tag{A62}$$

$$p^{*e} = \frac{\mathbb{E}\left(\frac{w k^{\theta\sigma} y}{a p^{1-\sigma}} \right)}{\mathbb{E}\left(\frac{k^{\theta\sigma} y}{p^{1-\sigma}} \right)}. \tag{A63}$$

For all but the last equation, these hold for each of the two states of the world in date 1. So, in total there are 13 of these equilibrium equations to solve for 2 values each of $y, y^*, y^{*e}, p^*, l, w$ and one value of p^{*e} or 13 unknowns, for given values of k, p. At date 0, the same system holds and likewise one can solve for it, noting that expectations at date -1 were that the economy would be in its steady state, as in from period 2 onwards.

Finally, one must check that the value of r that comes out of this system is indeed larger than 0.

$$1 + r = \left(\frac{w}{(\sigma-1)ap} \right) \left[\lambda y^* + (1-\lambda) \left(\frac{\sigma\, \mathbb{E}(w k^{\theta\sigma} y / p^{1-\sigma})}{w\, \mathbb{E}(k^{\theta\sigma} y / p^{1-\sigma})} - \sigma + 1 \right) y^{*e} \right]. \tag{A64}$$

F Proof of proposition 4

All that is needed is one counter-example. This proof provides several.

First, consider an equilibrium where $p_t = 1$ always, and where in capital markets the deposit market constraint binds, but the interbank market constraint does not bind. Then:

$$q_t b^p_{t-1} = (1-\xi)(1-\omega)\kappa - \upsilon_{t-1}, \tag{A65}$$

$$z_{t-1} = \left(\frac{\gamma(1+r)}{1-\gamma(1+r)} \right) [\omega\kappa - b^p_{t-1}(1-\delta_1)]. \tag{A66}$$

A change in (b_t, B_t) does not affect these equations. Therefore, debt management cannot prevent losses in net worth and contractions in deposits. All it does, from the market clearing condition in the deposit market, is to change the bond holdings of households since:

$$b_t^h = b_t - b_t^c - b_t^p, \tag{A67}$$

$$B_t^h = B_t - B_t^c. \tag{A68}$$

Second, note that δ_1, solved for in the text depends on v_t but not on (b_t, B_t). Therefore debt management cannot affect the extent of default on bonds.

Third, take the case where instead $\delta_t = 1$. Then, allow the central bank to set an arbitrary i_1, possible in disregard of its price level target. In that case, equilibrium prices have to satisfy the following two equations:

$$\frac{(1+i_0)v_0 + b_0 - b_0^c + (1+i_1')(B_0 - B_0^c)}{p_1'} = \frac{\bar{f} - g + s}{1-\beta} - \phi, \tag{A69}$$

$$\frac{(1+i_0)v_0 + b_0 - b_0^c + (1+i_1'')(B_0 - B_0^c)}{p_1''} = \frac{\bar{f} - g + s}{1-\beta}. \tag{A70}$$

Therefore, choices of (b_0, B_0) cannot achieve desired values for the price level independently of i_1' and i_1''.

G Proof of proposition 5

The model changes in only three ways. First, preferences now are:

$$\mathbb{E}_t \left[\sum_{\tau=0}^{\infty} \beta^\tau \left[\left(c_{t+\tau} + g_{t+\tau} - \frac{l_{t+\tau}^{1+\alpha}}{1+\alpha} \right) \right] + \varkappa U \left(\frac{h_{t+\tau}^h}{p_{t+\tau}} \right) \right], \tag{A71}$$

this leads to a standard demand for money function:

$$U' \left(\frac{h_t^h}{p_t} \right) = \frac{1}{(1-q_t)}. \tag{A72}$$

Second, the incentive constraint in the interbank market changes to

$$(1-\xi)x_t \leq q_{t-1} b_{t-1}^p + v_{t-1} + h_{t-1}^p. \tag{A73}$$

Third, the market clearing condition for money balances then is $h_t = h_t^h + h_t^p$, and seignorage now is:

$$s_t = \frac{h_t - h_{t-1}}{p_t}. \tag{A74}$$

Note that I already incorporate in the notation that unproductive banks will not want to hold currency, since it is strictly dominated by bonds for positive nominal interest rates.

The proof of the proposition is obvious. First, take the case where there is default. If $q_{t-1}b_{t-1}^0 + v_{t-1} \geq (1-\xi)(1-\omega)\kappa$, then $h_{t-1}^p = 0$. Then, from money demand, any change in h_t will affect inflation. Therefore, any printing of money that depends on there being a fiscal crisis will generate unexpected inflation at date 1. But, unexpected inflation affects output, via the Phillips curve, and price dispersion. Thus, it affects outcomes and welfare in a way that QE did not, since QE led to no inflation in this case.

Second, consider the case when $\delta_t = 1$. Then, during a fiscal crisis, increasing the money supply will both affect the value of the debt, but also generate extra seignorage revenues. Whereas more QE lowered the inflation surprise, more monetary financing will increase the inflation surprise.