Optimal Macro-Financial Policies in a New Keynesian Model with Privately Optimal Risk Taking *

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June 2023

We present a small-scale New Keynesian model with macroprudential externalities emerging from market allocations of aggregate risks. We demonstrate that an increase in household risk aversion can increase aggregate volatility: the model generates a safety trap. We show that there is a macroprudential role for monetary policy, even when macroprudential policies are set optimally. We analyse the optimal policy mix of monetary and macroprudential policies and its determinants. We show that the financial stability interest rate, a monetary policy that stabilises financial frictions, generates permanent deviations from target inflation, even when combined with optimal prudential policies.

JEL Classification: D52, E32, E52.
Keywords: Macroeconomics, Incomplete Markets, Monetary Policy.

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*This draft is preliminary. All errors are our own.

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Introduction

This paper studies the optimal formulation of monetary and macroprudential policies in a small-scale New Keynesian model with a micro-founded role for private debt. This topic is clearly of current practical importance. It is probably fair to say that practice is being developed and implemented ahead of any clear academic consensus. Our aim in this paper is to develop a small, tractable framework of the sort hitherto developed principally to study optimal monetary policy and incorporate a role for macroprudential policies. Amongst the key questions we analyse are: When should monetary policy respond to financial factors? Conversely, when should macroprudential policy respond to technology shocks and marginal costs? How does agents' risk aversion affect equilibrium risk allocation and optimal policy responses? What are the distributional implications of macroprudential and monetary policies and how do they affect optimal policies?

Overview

We present a small-scale New Keynesian model. The core model is entirely standard, with monopolistic competition in retail goods, and sticky prices. We add a financial friction to this core. Entrepreneurs each have a production technology where factor productivity has common and firm-specific stochastic components. Entrepreneurs seek outside finance but private information limits the extent to which they can share firm-specific risks with outside investors. Entrepreneurs and households are free to trade securities contingent on aggregate risks, which are common knowledge.

The monitoring of firm-specific risk reports follows the imperfect state verification model of Duncan and Nolan (2019). This is a useful framework for our purposes for three basic reasons. First, the model provides robust microfoundations for private debt contracts even when agents can increase and decrease their exposure to macroeconomic risks. Second, the model suggests that financial amplification follows both aggregate productivity shocks and risk/uncertainty shocks (aggregate risk markets notwithstanding). Third, it turns out that the model is straightforward to incorporate into the core New Keynesian model.

The extension adds one new equation (a law of motion for leverage) to the standard three equation New Keynesian model and adds leverage terms to the Phillips curve and the IS curve. The approximate social welfare (loss) functions are also amended from the basic New Keynesian loss function in intuitive ways. In factor markets, entrepreneurs discount the marginal revenue products of factors due to the increased (firm-specific) risk that accompanies increased production. A wedge of inefficiency emerges between the marginal revenue products of capital and labor and their factor prices. This wedge enters the Phillips Curve in a similar way to working capital loan frictions (as in Jermann and Quadrini, 2012, for example). Entrepreneurs consume from their own wealth. Fluctuations in the distribution of wealth and credit frictions thereby generate an aggregate demand wedge in the IS curve that is similar to Cúrdia and Woodford (2016).

There is good reason to believe that aggregate risk markets are open, at least to some extent, and that can have important implications for optimal outside finance contracts (Chari and Christiano, 2017). We allow for firms and households to allocate business cycle risk through market transactions. As a result, the model combines two sources of macroprudential externalities and subsequent motivations for intervention. First, as in Di Tella (2017) and Duncan and Nolan (2021), aggregate risk markets do not fully internalise the increased social costs of financial stress resulting from high leverage in downturns. Importantly, while this externality is limited to risk shocks in Di Tella (2017), it is present for technology and monetary policy shocks in our model. Second, as in Farhi and Werning (2016) and Schmitt-Grohe and Uribe (2012), aggregate risk markets do not fully internalise the aggregate demand externalities resulting from changes in the distribution of wealth.

The macroprudential externality in our model is an example of a *safety trap* (closely related to Caballero and Farhi, 2017). Individual risk averse households, seeking to protect their wealth from downturns, buy safe assets in aggregate risk markets. Entrepreneurs accept the other side of the trade, and aggregate risk is concentrated within firm balance sheets. Paradoxically, higher risk aversion generates a further demand for safety, which in turn concentrates risk and ultimately increases volatility in hours, income and consumption.

Bhandari et al. (2021) and Sheedy (2014) show how countercyclical monetary policy can improve risk sharing when agents are restricted to nominal contracts that are not contingent on aggregate states. In our model, agents can write contracts contingent on aggregate states, including monetary policy states, yet countercyclical monetary policy can still generate welfare gains, and still largely by helping to shore up debtors' net worth in downturns. In our model, countercyclical monetary policy has a macroprudential effect: it increases the marginal value of inside wealth carried into downturns, and thereby encourages debtors to reduce their exposure to aggregate risk.

Related literature

The literature on this topic is large, diverse, and growing. Martin et al. (2021) and Laeven et al. (2022) are recent and insightful overviews. The topic became, of course, of immense interest following the financial crisis in 2008/9. Whatever the faults of monetary policies around the globe ahead of that crisis, economists were quick to identify and endorse the use of new instruments to counter systemic, financial shocks. Allen and Rogoff (2011), for example, concluded that for some countries at least: "Controlling bubbles is a difficult task that needs as many tools as possible." The notion that monetary policy needs to be buttressed by macroprudential tools has become popular. But quite what that means in practice is far from settled.

It is widely noted, for example, that monetary policy changes can impact the supply and demand for credit but could also have unintended consequences for wider financial stability. Similarly, macroprudential measures (such as time varying capital requirements, lending restrictions and so on) might work to support financial stability but in turn they too could affect wider economic conditions, boosting or retarding growth. Intuitively, it seems clear that monetary and macroprudential policies inevitably affect each other's impact and effectiveness.

Theoretically, how these policies ought to be coordinated is still not settled. If macroprudential policy is efficient in addressing the relevant externalities, there is some indication that monetary policy should to a first approximation stick to its traditional objectives and not seek to help out as regards financial stability (see Korinek and Simsek, 2016 and Caballero and Simsek, 2019). The underlying intuition of these and similar contributions is that if macroprudential policies are able to knock out the externalities associated with systemic risk, then monetary policy ought to stabilise inflation or eliminate other nominal distortions. Of course, many contributors to this growing literature are aware that in practice macroprudential policy is unlikely to be fully effective, opening up the possibility of a systemic role for monetary policy not solely in addressing the impact of nominal rigidities but also with distortions associated with financial systemic risks. On the other hand, some argue that the financial stability role of monetary policy is quite fundamental (Stein, 2012, 2013).

It goes without saying that no single model can address, let alone settle, the many issues around this subject. Our aim is to build on one of the core models used in the analysis of optimal monetary policy in academic and policy analyses. To that New Keynesian model, we add a financial friction which generates a macroprudential externality even though agents can choose how exposed they are to aggregate risks. We then seek to answer many of the questions with which the paper started.

Preview of results

In Section 2 we document the *safety trap* property of our model (Proposition 1). When households have higher risk aversion, the economy is more volatile. Individual households' attempts to insure their consumption, by saving using safe and countercyclical financial assets, concentrate risk in the firm sector. This amplifies the volatility of labour demand and production, increasing the volatility of household consumption in equilibrium.

In Section 3 we characterise the optimal policy responses when households and entrepreneurs both share log utility, suspending the safety trap feature of our model. Monetary policy should respond to financial factors, which generate trade-offs that are similar to cost-push shocks. Conversely, macroprudential policy should only respond to technology and aggregate demand shocks when monetary policy is not optimal. Prudential policy generates medium run fluctuations in wealth and consumption inequality; when the welfare costs of these fluctuations are high, macroprudential interventions are smaller and monetary interventions are larger.

In Section 4 we relax the assumption of log utility for the worker household, reintroducing our safety trap, which generates financial amplification of technology shocks and monetary policy responses. We restrict our attention to monetary policy regimes that maintain zero anticipated inflation. Following persistent shocks, the short term financial stability benefits of accommodative monetary policy are reversed as the monetary authority restores target inflation. Accommodative monetary policy is best suited to respond to temporary technology shocks, where monetary stimulus can be withdrawn as the shock dissipates. Conversely, macroprudential policy is best suited to responding to persistent technology shocks. Macroprudential policy is not well suited to responding to temporary technology shocks, as its effects on firms' leverage and consumption inequality persist after the shock has dissipated.

In Section 5 we consider a monetary policymaker who seeks to maintain financial stability in all periods. This analysis follows Akinci et al. (2021), who study a comparable policy in a quantitative model based on Gertler and Kiyotaki (2010). In our model, a monetary policy that maintains a financial stability interest rate generates permanently high inflation in response to a temporary recessionary shock.[1] Prudential policies can dampen but cannot eliminate the inflationary consequences of financial stability interest rate policy.

Taken together, our results suggest that monetary policy should respond aggressively to uncertainty shocks, even when policymakers have access to macroprudential policy tools. In some ways this might be a surprise: uncertainty shocks are real shocks to the technology process in our model. During uncertain business cycles, real monitoring costs are high, and these monitoring costs are a welfare-relevant cost of production. Within-period, optimal monetary policy stimulates the economy beyond the point where the total marginal costs of production exceed marginal consumption utility. Section 6 investigates this result and identifies the key features of the model that this result relies on.

[1] Akinci et al. (2021) also find that financial stability monetary policy is very accommodative to supply shocks.

1 The model

The model consists of a representative household, who supplies labour and capital to a large population of entrepreneurs who produce a common product with a risky productive technology. Entrepreneurs sell their produce to monopolistically competitive retailers owned by the representative household, who produce differentiated retail products for consumption by both the representative household and the entrepreneurs themselves. We start by describing the aggregate equilibrium conditions before turning to their derivation.

1.1 Equilibrium conditions

Let x denote real output, i the nominal interest rate, π the inflation rate, ξ an uncertainty shock, l firm leverage. Each of these variables is expressed in terms of log deviation from their respective steady state levels. The principal equations of our model are Equations 1.1-1.3.

The IS curve

$$x_t = \mathbb{E}[x_{t+1}] - \frac{\zeta}{\sigma + \zeta - 1}\left(i_t - \mathbb{E}_t[\pi_{t+1}]\right) - \frac{\zeta - 1}{\sigma + \zeta - 1}\left(l_t + \frac{\rho_\xi - \psi}{1 - \psi}\xi_t\right), \quad (1.1)$$

The Phillips curve

$$\pi_t = \beta \mathbb{E}_t[\pi_{t+1}] + \lambda \mathrm{pp}_t, \quad (1.2)$$

The Leverage curve

$$\Delta l_t = -\frac{\psi}{\zeta}(l_{t-1} + \xi_{t-1}) + \frac{\sigma\omega\psi}{\zeta}\Delta\xi_t - \frac{(\sigma - 1)}{\zeta}\Delta x_t - \delta_t, \quad (1.3)$$

where σ denotes the representative household's coefficient of relative risk aversion, $\frac{\omega}{1+\omega}$ is the steady state entrepreneurial consumption share, and ψ is the elasticity of the equity risk premium with respect to leverage and risk (see Appendix A.1). The composite parameter is defined as $\zeta := 1 + \sigma\omega(1 - \psi)$, and represents the elasticity of the ratio of consumption marginal utilities of the representative household and entrepreneurs with respect to leverage. The operator Δ takes the growth rate of its argument, $\Delta l_t = l_t - l_{t-1}$.

The model consists of a population of identical households and a population of entrepreneurs (described further in Section 1.2). Leverage is a measure of the extent to which debt is used to boost (expected) output. We measure leverage as the ratio of expected entrepreneurial output divided by the opportunity cost of entrepreneurial wealth. After log-linearization, leverage is $l_t = x_t - c_t^e + \rho_t$, where c_t^e is entrepreneurial consumption and ρ_t is the equity risk premium. Given entrepreneurial wealth at the start of the period, higher expected output is the result of higher leverage—higher borrowing from the household sector. All output is consumed, therefore leverage and the equity risk premium, $l_t and \rho_t$, uniquely determine the distribution of consumption.

The time varying distribution of consumption generates the departure of our IS curve from the benchmark New Keynesian IS curve.[2] The aggregate intertemporal elasticity of substitution $\left(\frac{\zeta}{\sigma+\zeta-1} = \frac{\frac{1}{\sigma}+\omega(1-\psi)}{1+\omega(1-\psi)}\right)$ becomes a weighted average of those of the household $\left(\frac{1}{\sigma}\right)$ and the entrepreneurs (1). Expected consumption growth is equal to the sum of expected output growth and the expected growth of the households' consumption share of total output. All else equal, an increase in leverage or uncertainty will reduce the expected growth of the households' consumption share of total output. As a consequence, an increase in leverage or uncertainty will increase expected output growth for every level of the real interest rate.

Leverage and uncertainty also affect the Phillips curve in our model, through their effect on wholesale producer prices, the prices paid in competitive markets for the homoegeneous intermediate good produced by entrepreneurs. As in the benchmark New Keynesian model, marginal labour costs are increasing in output x_t and decreasing in technology a_t.[3] Leverage and uncertainty affect both labour supply and labour demand for every level of the output gap. On the supply side, an increase in leverage increases the households' consumption share of output, reducing households' marginal utility and increasing wage demands for every level of the output gap (a wealth effect resulting from consumption inequality).[4] On

[2]For example, Galí (2008, Chapter 3).

[3]As is standard, we denote the inverse Frisch elasticity as φ, and the production Cobb-Douglas weight on labour as $1-\alpha$.

[4]Similarly, a decrease in uncertainty also increases the households' consumption share of output and increases wage demands for every level of the output gap.

the demand side, entrepreneurs hire labour before realising their individual specific productivity outturn. Each additional worker increases the risk of production outcomes to the entrepreneur, a risk that can only imperfectly be defrayed to outside investors. Increased leverage and/or uncertainty decrease the demand for labour for every level of the output gap (a labour wedge of inefficiency).[5]

$$\mathrm{pp}_t = \underbrace{\left(\sigma + \tfrac{\varphi+\alpha}{1-\alpha}\right) x_t - \tfrac{1+\varphi}{1-\alpha}\, a_t}_{\text{benchmark model marginal costs}} + \underbrace{\sigma\omega(1-\psi)l_t - \sigma\omega\psi\xi_t}_{\text{consumption inequality wealth effect}} + \underbrace{\tau_t}_{\text{labour wedge}}, \tag{1.4}$$

where the labour wedge is increasing in both leverage and uncertainty,

$$\tau_t = \theta_l l_t + \theta_\xi \xi_t, \qquad \theta_l, \theta_\xi > 0. \tag{1.5}$$

After purchasing the wholesale good from entrepreneurs, retailers produce a differentiated good which is sold in monopolistically competitive markets subject to Calvo pricing frictions.

Households and entrepreneurs can trade securities contingent on aggregate risks that are observed by all. In competitive equilibrium, aggregate risk sharing implies that consumption aggregates evolve according to Equation 1.6. Equation 1.6 resembles a standard risk sharing condition but for two additions. First, the equity risk premium ρ reflects a wedge between the evolution of the marginal utility of the average entrepreneurial consumption bundle c_t^e, and the evolution of average entrepreneurial marginal utility. This wedge results from incomplete risk sharing with respect to individual specific risks faced by entrepreneurs. The second addition is δ_t, the prudential policy instrument, that acts to limit either population's exposure to aggregate risks.

$$\sigma\Delta c_t = \Delta c_t^e - \rho_t - \delta_t \tag{1.6}$$

By Equation 1.6, we can forecast changes in the expected consumption share of output, despite aggregate risk sharing. When leverage l_t or uncertainty ξ_t increase, the risk borne by entrepreneurs increases, and the equity risk premium ρ_t will increase. This generates a wedge between the growth of expected entrepreneurial

[5] A similar labour wedge of inefficiency could be derived from working capital loan frictions (as in Jermann and Quadrini, 2012, for example).

consumption and expected entrepreneurial marginal utility, and predictable fluctuations in the distribution of consumption. Ultimately, from 1.6 we can derive the leverage curve 1.3, which predicts a mean-reverting path of leverage over time, with leverage increasing in uncertainty and decreasing in output. Aggregate risk markets imply that when household consumption falls, entrepreneurial consumption also falls. As a result, for $\sigma > 1$, a decrease in output will cause an increase in leverage (as in 1.3). In this way, aggregate risk sharing is a source of the financial amplification of shocks in our model.

1.2 Derivation of the model

In this section we present the foundations of our model from which we derive the equilibrium conditions above. Our model consists of a household sector, which supplies labour and savings; a population of entrepreneurs, who produce a homogeneous wholesale good with a risky technology; a retail sector, which produces differentiated retail products from the wholesale good, and a policymaker with access to prudential and interest rate policy instruments.

1.2.1 Households

The representative worker household brings wealth q_t into period t, enjoys consumption c and dislikes labour hours n. They have the following value function, expressed recursively,

$$v(q_t) = \max_{z_t, c_t, n_t, q_{t+1}} \mathbb{E}_t \left\{ \frac{c_t^{1-\sigma}}{1-\sigma} - \frac{n_t^{1+\varphi}}{1+\varphi} + \beta v(q_{t+1}) \right\}$$

Households' real wealth carried forward into period $t+1$, q_{t+1}, is the sum of the gross real return to their period t wealth $(1+r)q_t$, real labour income $w_t n_t$, and real profits remitted from retailers Π_t, less consumption c_t, plus the net returns from their trade in aggregate risk:

$$q_{t+1} = (1+r)q_t + w_t n_t + \Pi_t - c_t \underbrace{- \int_{s \in S} p_t(s) z_t(s_t) ds + z_t(s_{t+1})}_{\text{trade in aggregate risk}} .$$

Aggregate risk securities $z_t(s)$ are contingent on the aggregate state vector s. In our analysis s can include productivity shocks, uncertainty shocks, markup and cost push shocks, government purchases shocks, and monetary policy shocks. In practice, we consider this aggregate risk trade as a proxy for a wide range of financial decisions that shift agents' exposure to business cycle shocks, and shift risks between groups.[6] Wealth q_{t+1} is determined by decisions made in period t, but is contingent on time $t+1$ outcomes of exogeneous state variables, and is therefore measurable in the $t+1$ state-space.

1.2.2 Entrepreneurs

An entrepreneur's intertemporal problem can be described as follows:

$$v^e(q_t^e) = \max_{z_t^e, c_t^e, q_{t+1}^e} \mathbb{E}_{\Phi,t} \left\{ \log c_t^e + \beta^e v^e(q_{t+1}^e) \right\}$$

subject to

$$q_{t+1}^e = R_t(\phi_t, s_t) q_t^e - c_t^e - \int_{s \in S} p_t(s) z_t^e(s_t) ds + z_t^e(s_{t+1})$$

Superscript e denotes the entrepreneur, and $v^e(q^e)$ is the value function. $R(\phi, s)$ is the return to entrepreneurial wealth, q_t^e, and is the outcome of a privately optimal external finance contract, determined at the beginning of the period, and conditional on idiosyncratic states realised within the period. ϕ denotes the idiosyncratic state drawn from set Φ and privately known by the entrepreneur. Trade in aggregate risk markets is captured by the quantities $z^e(s)$, denoting the amount purchased of an asset with payoff 1 conditional upon the future state of the world being realised as state s. The current period price of this security is denoted $p(s)$. As indicated earlier, trade in securities indexed by the aggregate state are not hampered by any problem of asymmetric information; unlike idiosyncratic states, aggregate states are costlessly observed and verified by all agents. These markets are active.

[6]The decision between mortgage fixed rate terms is an example. A longer fixed rate term will reduce the household's exposure to aggregate shocks that result in high interest rates, which would be harmful to households with short mortgage fixed rate terms. In this way, a longer mortgage fixed rate provides insurance against aggregate shocks that increase interest rates. This insurance doesn't remove risk from the aggregate economy, but it does shift the risk from the mortgage borrowing household to other agents who are happy to accept interest rate risk at an agreeable price.

At the start of period t, the aggregate state s_t is realised and the payoffs from aggregate risk securities $z^e_{t-1}(s_t)$ are paid/received. This leaves entrepreneurs with net wealth q^e_t. They combine this wealth with borrowed funds to hire capital goods and labour for production within period t. Importantly, entrepreneurs borrow and employ labour before realising their within period idiosyncratic productivity shock.

Entrepreneurs produce output according to the function

$$f(k^e_t, n^e_t; a_t, \phi_t) = a_t \nu(\phi_t)(k^e_t)^\alpha (n^e_t)^{1-\alpha}$$

where ν maps the individual specific shock ϕ into productivity and $a \in z$ is an aggregate productivity shock. An individual entrepreneur hires labour and rents capital after observing the aggregate state a_t, but before observing their individual specific shock ϕ_t.

The optimality condition for entrepreneurs' labour hiring can be expressed as follows:

$$\frac{w_t}{\text{PP}_t}\mathbb{E}_{\Phi,t}\left[\frac{1}{c^e_t(\phi_t)}\right] = \mathbb{E}_{\Phi,t}\frac{f_{n^e}(k^e_t, n^e_t; a_t, \phi_t)}{c^e_t(\phi_t)}$$

where PP_t is the producer price.

The marginal product of labour and the marginal utility value of revenue to the entrepreneur both vary across states of the world. Entrepreneurs place a high marginal utility weight on revenue in (privately) bad states of the world, where $c^e(\theta)$ is low, and a low marginal utility weight on revenue in good states.[7]

$$\frac{w_t}{\text{PP}_t} = \mathbb{E}_{\Phi,t}\left[f_{n^e}(n^e_t;\phi_t)\right]\underbrace{\left(1 + \text{cov}_{\Phi,t}\left(\frac{f_{n^e}(n^e_t;\phi_t)}{\mathbb{E}_{\Phi,t} f_{n^e}(n^e_t;\phi_t)}, \frac{1/c^e_t(\phi_t)}{\mathbb{E}_{\Phi,t}\left[1/c^e_t(\phi_t)\right]}\right)\right)}_{:=1-\tau}$$

A positive covariance between entrepreneurs' individual specific productivity draws $\nu(\theta)$ and consumption marginal utility $1/c^e_t(\phi_t)$ generates a labour wedge τ between the average marginal revenue product of labour across entrepreneurs, and the wage rate. If entrepreneurs cannot defray all production risk to external

[7] Arellano et al. (2019) generate a similar labour wedge in a model with risk neutral entrepreneurs and agency costs based on Jensen (1986).

financiers, then this labour wedge will be positive.

Entrepreneurs' homogeneous output is sold in competitive markets to retail firms, who produce differentiated retail consumption goods for sale to households and entrepreneurs in monopolistically competitive markets. Retailers are owned by the households, and face Calvo (1983) pricing rigidities. Their full problem is described in Appendix B.2.

1.2.3 Macroprudential policy

Macroprudential policy in our model influences the allocation of exposure to aggregate risks. Rather than introducing a specific instrument, we take a mechanism design approach to the information constraints faced by the macroprudential policymaker.

The setup here is isomorphic to a model where banks make risky (i.e., undiversifiable) loans to final goods firms. The high returns in downturns, associated with higher risks, would discourage such banks from insuring their balance sheets against recessionary risks. As a result, and as in the model above, leverage would be too high going into the downturn and banks' ability to lend in the downturn would be too low from a social perspective. In other words, there would be a macroprudential externality. In such a situation, policymakers acting optimally would seek to curtail risky lending and that could be implemented via Basel-type capital requirements and/or loan-to-value type restrictions (applied symmetrically across all banks). The approach we take here is for tractability and avoids explicit modelling of the banking sector, envisaging risk management restrictions directly between households and entrepreneurs.

Constraint 1 *Hidden storage. Entrepreneurs can hide wealth across periods at the market risk free real interest rate.*

Within periods, entrepreneurs can hide income and consumption from external creditors. Across periods, entrepreneurs can hide wealth from macroprudential policymakers. In the absence of hidden storage, entrepreneurs who hide income from external creditors would consume their hidden income within the period.[8]

[8]Allowing storage across periods to be observable, as in Green and Oh (1991) and Khan and Ravikumar (2001), would likely generate further interesting policy tradeoffs.

Constraint 1 prohibits the policymaker from imposing different risk free interest rates for households and entrepreneurs. Savings are a complement to within period misreporting of income, so Constraint 1 eliminates a margin that the policymaker could use to dampen the costs of the within period moral hazard problem between entrepreneurs and their external financiers (Green and Oh, 1991). In our view, prudential policies that did attempt to impose different risk free interest rates across groups are unlikely to be implementable in practice, whereas prudential policies that focus on exposure to risk are more likely to be implementable.

It follows from Constraint 1 is that in expectation, both entrepreneurs' and households' expected growth of marginal utility are equated to the same discount rate. As a result, intertemporal risk sharing holds in expectation for any feasible prudential policy,

$$\sigma \mathbb{E}_t[\Delta c_{t+1}] = \mathbb{E}_t[\Delta c^e_{t+1}] - \mathbb{E}_t[\rho_{t+1}]. \tag{1.7}$$

Lemma 1 follows directly from (1.6,1.7).

Lemma 1 *The macroprudential wedge is unpredictable,* $\mathbb{E}_t[\delta_{t+1}] = 0$.

While the macroprudential wedge is unpredictable, this does not imply that the macroprudential policy tools are ex post responses to shocks. Ex post transfers between entrepreneurs and households, in isolation, would have no effect on allocations in our model; agents would be able to trade away these transfers in competitive markets for claims contingent on aggregate states. Rather, macroprudential policy is characterised by ex ante interventions that dampen or amplify the response of net wealth to unanticipated economic shocks. These interventions could take the form of regulations, including risk-based leverage limits.

Corollary 1 *Macroprudential policy dampens (or amplifies) the response of entrepreneurial net wealth to unanticipated fluctuations in income and uncertainty. Macroprudential policy does not affect the response of entrepreneurial net wealth to anticipated fluctuations in income and uncertainty.*

The macroprudential policymaker in our model can prevent the deterioration of entrepreneurial balance sheets in a crisis, but cannot on its own recapitalise entrepreneurs after their balance sheets have deteriorated.

1.2.4 Welfare

In order to construct a measure of welfare, we weight the household and entrepreneurial populations using the Negishi (1960) method. Intuitively, our policymaker would not wish to transfer wealth between populations in the model's steady state. This ensures that policy interventions are motivated by efficiency.

We explicitly model entrepreneurs in our welfare function specifically for two reasons: the first is that entrepreneurs consume a significant and variable share of total output, and therefore entrepreneurial consumption contributes to the household consumption welfare losses from fluctuations in output. The second is that a monetary and financial policy regime that explicitly harms entrepreneurs without generating a sufficient offsetting benefit for households is inappropriate, and may interact with the feasibility of other government policies that affect the distributions of income and consumption.

Our quadratic loss function is described by (1.8). The first three terms are similar to the benchmark New Keynesian model.

$$
\begin{aligned}
2\Lambda = {} & (1+\omega)\frac{\varepsilon}{\lambda}\pi_t^2 + (1+\omega)\frac{1+\varphi}{1-\alpha}x_t(x_t - 2a_t) + (\sigma - 1)\, x_t^2 \\
& + \omega\left((\zeta - \psi)l_t + (\sigma - 1)x_t\right)\left((1-\psi)l_t - \psi\xi_t\right) \\
& + \omega l_t(\kappa_{ll}l_t + \kappa_{l\xi}\xi_t) + \text{t.i.p.}
\end{aligned}
\tag{1.8}
$$

The parameters $\kappa_{ll}, \kappa_{l\xi}$ capture the convexity of the dispersion of consumption outturns with respect to individual specific productivity outturns. Inflation reduces the efficiency of labour hours due to increased price dispersion; high output or low aggregate productivity reduces the return to labour hours; log consumption volatility is costly for households, with those costs increasing in the degree of risk aversion.

The second line captures volatility in the distribution of consumption between households and entrepreneurs and its effect on consumption welfare losses for households. The third line captures the welfare costs accruing to entrepreneurs as a result of individual specific dispersion in productivity outturns. The resulting welfare losses are convex in leverage, uncertainty and their interaction.

2 The safety trap

Caballero and Farhi (2017) introduced the concept of a *safety trap*: in an acute liquidity trap, households' efforts to eliminate risk work against them in equilibrium, exacerbating the shortage of safe assets and amplifying volatility in output.

Our model has a similar property. Individual risk averse households seek protection from aggregate fluctuations through their financial asset holdings. Entrepreneurs take the other side of the trade, absorbing aggregate risk. This leaves risk concentrated among entrepreneurs, resulting in large procyclical fluctuations in entrepreneurial net wealth, and financial amplification of aggregate shocks.

Paradoxically, an increase in household risk aversion generates an increased demand for safe assets from households. In equilibrium, this further concentrates risk among entrepreneurs, increasing volatility in leverage and ultimately income. This result is formalised by Proposition 1.

Proposition 1 *The safety trap. An increase in the representative household's coefficient of relative risk aversion can increase the volatility of the path of output.*

The Proposition can be proved by inspection of (E.4); Appendix E.3 also provides a discussion of the absense of an effect of risk aversion on the on-impact response of output to shocks in the flexible price model. We also provide a numerical example in Figure 1.

3 Optimal policy under log utility

Household risk aversion is central to the financial accelerator mechanism in our model, and restricting households to log utility means that fluctuations in leverage and the equity risk premium are solely the result of uncertainty shocks. We find this log utility benchmark to be a useful starting point for our analysis, before returning to the general model with greater household risk aversion in later sections.

In this section we present three optimal policy results. First, we characterise optimal macroprudential policy in a flexible price benchmark economy. Second, we characterise optimal monetary and macroprudential policy under sticky prices. Optimal monetary policy stimulates the economy following uncertainty shocks, which

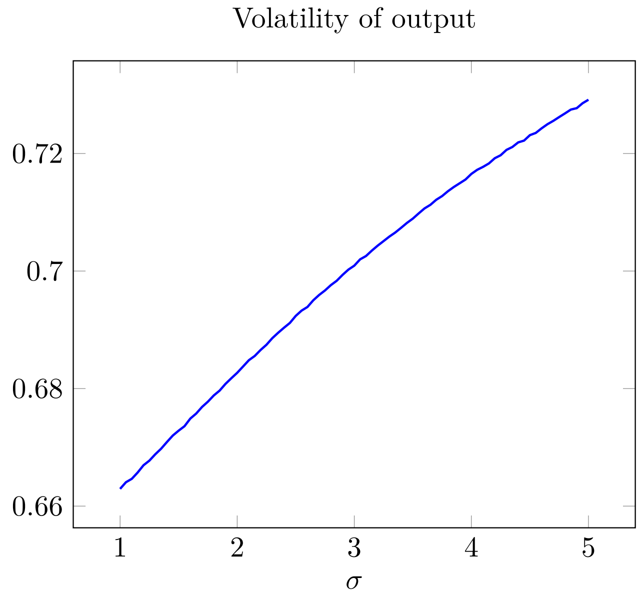

Figure 1: Output volatility and risk aversion in the flexible price model with risk shocks only. Prior means were used to parameterise the model for this example.

complements the optimal macroprudential response. Third, we characterise optimal macroprudential policy under an interest rate rule. In this case, we focus on technology shocks, where the interest rate rule does not optimally manage aggregate demand, creating a role for macroprudential policy that differs from the earlier regimes.

Assumption 1 *All of the results in this section only rely on the assumption that household utility is logarithmic,* $\sigma = 1$.

Assumption 1 is strong. It improves tractability at the cost of removing an important feedback mechanism from the model. Under log utility, the feedback from output to leverage (and financial stability) is broken. Net worth moves one-for-one with aggregate output, $\beta_x = 1$. Broadly speaking, this assumption means that the monetary policy authority can treat leverage as exogenous. This makes the model very tractable and helps us identify costs and benefits of policy interventions. The financial sector does not amplify technology shocks under log utility, and all financial disturbances are the result of either uncertainty shocks, or of macroprudential policy, which we will see, may optimally choose to generate a link between financial stability and technology shocks in order to dampen the output response to technology shocks. In Section 4 we analyse optimal policy responses to technology shocks with greater household risk aversion and financial amplification.

The full derivations for this section are available in Appendix F.

3.1 The flexible price benchmark

We start with a flexible price benchmark before re-introducing nominal rigidities and monetary policy. Appendix E derives the flexible price aggregate demand and supply equilibrium relationship,

$$\chi x_t = \chi a_t - \vartheta_l l_t - \vartheta_\xi \xi_t, \tag{3.1}$$

where $\vartheta_l, \vartheta_\xi$ are the elasticities of marginal production costs with respect to leverage and uncertainty shocks respectively, incorporating both the direct risk bearing costs of leverage and uncertainty, as well as the wealth effect of consumption inequality resulting from leverage and uncertainty on labour supply,

$$\vartheta_l := \theta_l + \zeta - 1, \qquad \vartheta_\xi := \theta_\xi - \sigma\omega\psi.$$

Real output is increasing with technology, but decreases with leverage and uncertainty shocks. Both leverage and uncertainty increase risk borne by entrepreneurs, reducing labour demand. In addition, an increase in leverage reflects an increase in household wealth, generating a negative wealth effect on labour supply. Holding all else equal, an increase in uncertainty increases the entrepreneurs' share of consumption, generating a positive wealth effect on labour supply which dampens the effect of uncertainty shocks on output.

The prudential policymaker also faces a leverage constraint. The Leverage curve 1.3 must hold in expectation:

$$\mathbb{E}_t[\Delta l_{t+1}] = -\frac{\psi}{\zeta}(l_t + \xi_t) + \omega\frac{\psi}{\zeta}\mathbb{E}_t[\Delta \xi_{t+1}]. \tag{3.2}$$

Ultimately, we will characterise macroprudential policy by the wedge δ_t where

$$\Delta l_t = -\frac{\psi}{\zeta}(l_{t-1} + \xi_{t-1}) + \omega\frac{\psi}{\zeta}\Delta\xi_t - \delta_t.$$

where $\mathbb{E}_t[\delta_{t+1}] = 0$. The flexible price macroprudential policymaker's problem is described by Programme 1.

Programme 1

$$\min_{x,l} \mathbb{E}\sum_{t=0}^{\infty}\beta^t\frac{1}{2}\left[\begin{array}{l}(1+\omega)\chi\left(x_t^2 - 2x_t a_t\right) + \omega\left(\kappa_{ll} + (\zeta-\psi)(1-\psi)\right)l_t^2 \\ +2\omega\left(\kappa_{l\xi} - (\zeta-\psi)\psi\right)l_t\xi_t\end{array}\right]$$

Subject to (3.1), (3.2).

Solving Programme 1 yields the following optimal macroprudential policy wedge:

$$\delta_t = \left(\frac{\omega\hat{\kappa}_{l\xi} + (1+\omega)\chi^{-1}\vartheta_l\vartheta_\xi}{\omega\hat{\kappa}_{ll} + (1+\omega)\chi^{-1}\vartheta_l^2}\left(\frac{\phi_2-\phi_1}{\phi_2-\rho_\xi}\right) - \frac{1-\omega(\phi_2-1)}{\phi_2-\rho_\xi}\frac{\psi}{\zeta}\right)\varepsilon_{\xi,t}, \quad (3.3)$$

where ϕ_1, ϕ_2 are the stable and explosive eigenvalues attached to the shadow cost of the leverage constraint,

$$\phi_1 = \frac{\zeta-\psi}{\zeta}, \quad \phi_2 = \frac{1}{\beta\phi_1}.$$

The ratio

$$\frac{\omega\hat{\kappa}_{l\xi} + (1+\omega)\chi^{-1}\vartheta_l\vartheta_\xi}{\omega\hat{\kappa}_{ll} + (1+\omega)\chi^{-1}\vartheta_l^2}$$

is the current period marginal rate of transformation between the social costs of uncertainty and the social costs of leverage. Without loss of generality, $\hat{\kappa}_{l\xi}$ is the individual cost of increased entrepreneurial risk bearing resulting from greater co-variance between leverage and uncertainty, and is weighted by the entrepreneurial Negishi weight ω. The product $\chi^{-1}\vartheta_l\vartheta_\xi$ captures the cost of reduced hours resulting from the labour demand and supply effects of leverage and uncertainty, which are particularly high when the labour margin is more elastic (when χ is small). The resulting costs are borne by all and are therefore Negishi weighted $(1+\omega)$. In sum, the numerator captures the extent to which a change in leverage can offset the marginal social costs of uncertainty, and the denominator captures the social costs of the resulting volatility of leverage. These relative costs are weighted by the relative persistences of uncertainty and leverage. If the persistence of leverage ϕ_1 is high relative to the persistence of uncertainty ρ_ξ, then the policymaker will moderate their prudential response to uncertainty shocks.

In the competitive equilibrium, uncertainty shocks increase current period leverage but they reduce leverage over longer time horizons. When uncertainty is high, the return to inside wealth is also high, and entrepreneurs' inside wealth grows quickly. As leverage is persistent, macroprudential policy has a enduring effect on the path of leverage, and can exacerbate the medium term fall in leverage in response to a contractionary uncertainty shock. This persistence may not be desirable. The second term,

$$-\frac{1-\omega(\phi_2-1)}{\phi_2-\rho_\xi}\,\frac{\psi}{\zeta},$$

reflects the persistent effect of current period uncertainty on future leverage, and dampens the optimal macroprudential response to uncertainty shocks.

Optimal macroprudential policy does not respond to technology shocks in this economy. Under log utility, technology shocks do not generate fluctuations in leverage. The competitive allocation appropriately adjusts hours worked in response to changes in technology. We'll see in Section 3.3 that deviations from optimal aggregate demand management can generate a motivation for macroprudential policy even in the absence of feedback from output to leverage, and we'll see in Section 4 that when the representative household is more risk averse, financial amplification of technology shocks generates fluctuations in leverage and in turn motivates macroprudential policy.

Figure 2 presents responses to a recessionary uncertainty shock, with and without macroprudential policy. In the absence of policy, entrepreneurial net wealth decreases sharply in response to the uncertainty shock, with leverage rising as a result. The combination of high leverage and high uncertainty decreases labour demand, and output falls in response. Under the optimal prudential policy, entrepreneurial net wealth is protected, and leverage falls with output. Falling leverage helps to

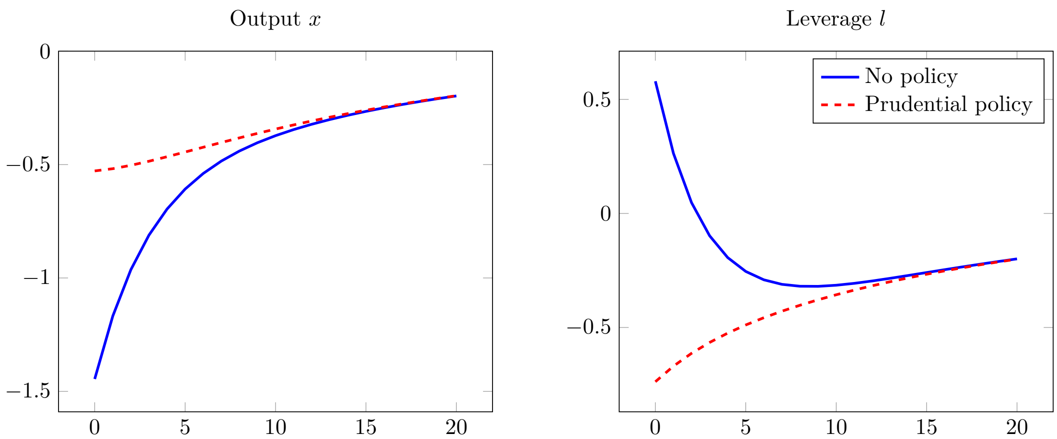

Figure 2: Responses to a recessionary uncertainty shock.

dampen the response of labour demand to the uncertainty shock, and as a result, the output response is dampened.

3.2 Optimal monetary and prudential policy with nominal rigidities

In this section we reintroduce nominal rigidities and solve for jointly optimal monetary and prudential policy under commitment. We separate the problem into two parts. Under log utility, the effect of the monetary policymaker's action on leverage is mediated through the optimal policy of the prudential policymaker. So, we first solve for the paths of output and inflation as functions of leverage, uncertainty and technology shocks—we interpret this as monetary policy—then we solve for the optimal path of leverage—we interpret this as the prudential policy.

The combined policymaker solves the following programme:

Programme 2 *Joint optimal monetary and prudential policy under log utility.*

$$\min_{\pi,x,l} \mathbb{E} \sum_{t=0}^{\infty} \beta^t \frac{1}{2} \left((1+\omega) \left(\frac{\varepsilon}{\lambda} \pi_t^2 + \chi \left(x_t^2 - 2x_t a_t \right) \right) + \omega \hat{\kappa}_{ll} l_t^2 + 2\omega \hat{\kappa}_{l\xi} l_t \xi_t \right)$$

Subject to (3.2), and

$$\pi_t = \beta \mathbb{E}_t[\pi_{t+1}] + \lambda \chi x_t - \lambda \chi a_t + \lambda \vartheta_l l_t + \lambda \vartheta_\xi \xi_t.$$

The divine coincidence holds for technology shocks under log utility, so we focus our analysis on uncertainty shocks. Leverage and uncertainty enter the Phillips curve in a similar way to traditional New Keynesian cost-push shocks. Given the absence of feedback from monetary policy to leverage under log utility, optimal monetary policy faces similar trade-offs to monetary policy under cost-push shocks. Optimal inflation resembles a price-level targeting rule. Inflation increases in response to leverage and uncertainty, but eventually turns negative in order to restore the original price level (which is normalised to zero).

$$p_t = \varphi_1 p_{t-1} + \frac{\beta^{-1}\lambda}{\varphi_2 - \phi_1}\left(\vartheta_l l_t + \vartheta_\xi \left(1-\gamma\right)\xi_t\right). \tag{3.4}$$

where φ_1, φ_2 are the stable and explosive eigenvalues associated with optimal aggregate demand management familiar to New Keynesian models, and γ reflects the policymakers internalisation of expected effect of current uncertainty on future leverage.[9]

By allowing prices to rise on impact to recessionary uncertainty shocks, the monetary policy authority bears a welfare cost from inflation but generates an increase in welfare by smoothing the path of output, consumption, and hours worked. This countercyclical monetary policy has no impact on leverage and risk bearing, with firms' net wealth rising one for one with output to ensure that leverage remains invariant to monetary stimulus.

Optimal prudential policy is countercyclical, with the prudential policymaker lowering realised leverage in response to increases in the expected path of the cur-

[9]

$$\varphi_1 = \frac{(1+\beta+\lambda\chi\varepsilon) - \sqrt{(1+\beta+\lambda\chi\varepsilon)^2 - 4\beta}}{2\beta}, \qquad \varphi_2 = \frac{1}{\beta\varphi_1},$$

$$\gamma = \frac{\phi_1 - \rho_\xi + \frac{\vartheta_l}{\vartheta_\xi}(1+\omega(1-\rho_\xi))\frac{\psi}{\zeta}}{\varphi_2 - \rho_\xi}, \qquad \lim_{\varepsilon\to\infty}\gamma = 0.$$

rent and future price level, and the risk bearing costs of uncertainty:

$$\delta_t = \frac{(1+\omega)\varepsilon\vartheta_l}{\omega\hat{\kappa}_{ll}}(\phi_2-\phi_1)\sum_{j=0}^{\infty}(\beta\phi_1)^{j+1}(\mathbb{E}_t[p_{t+j}]-\mathbb{E}_{t-1}[p_{t+j}])$$
$$+\left(\frac{\hat{\kappa}_{l\xi}}{\hat{\kappa}_{ll}}\left(\frac{\phi_2-\phi_1}{\phi_2-\rho_\xi}\right)-\frac{1-\omega(\phi_2-1)}{\phi_2-\rho_\xi}\frac{\psi}{\zeta}\right)\varepsilon_{\xi t}$$

Optimal monetary policy equates the marginal cost of inflation and output gaps resulting from uncertainty shocks. The prudential policymaker can therefore assess their optimal policy against the marginal impact of the policy on the economic costs of inflation. An increase in δ reduces leverage by ζ, which on impact reduces marginal costs by ϑ_l. Leverage propagates with persistence ϕ_1, so the effect of leverage on future prices decays at this rate. The welfare costs of future inflation are discounted at the social rate of time preference β. The Welfare costs of inflation are increasing in the elasticity of substitution ε and are borne by all consumers, assigned Negishi weight $1+\omega$.

Equation 3.5 presents the optimal prudential policy in terms of the uncertainty shock alone. When the retail consumption elasticity of substitution approaches infinity, $\varepsilon \to \infty$, countercyclical monetary policy becomes prohibitively expensive, optimal inflation tends to zero and the optimal prudential policy collapses to the flexible price case (3.3). Conversely, as the retail consumption elasticity of substituion approaches zero, $\varepsilon \to 0$, countercyclical monetary policy can fully eliminate the social costs of uncertainty shocks that are transmitted through marginal costs, and prudential policy responds to the risk bearing and distributional costs of uncertainty and leverage only.

$$\delta_t = \left(\frac{\chi\omega\hat{\kappa}_{l\xi}+(1+\omega)\vartheta_l\vartheta_\xi\varsigma(1-\gamma)}{\chi\omega\hat{\kappa}_{ll}+(1+\omega)\vartheta_l^2\varsigma}\left(\frac{\phi_2-\phi_1}{\phi_2-\rho_\xi}\right)-\frac{1-\omega(\phi_2-1)}{\phi_2-\rho_\xi}\frac{\psi}{\zeta}\right)\varepsilon_{\xi t} \quad (3.5)$$

where

$$\varsigma = \frac{\lambda\chi\varepsilon}{\beta}\frac{\phi_2}{(\varphi_2-\phi_1)(\phi_2-\varphi_1)}, \qquad \lim_{\varepsilon\to 0}\varsigma = 0, \quad \lim_{\varepsilon\to\infty}\varsigma = 1.$$

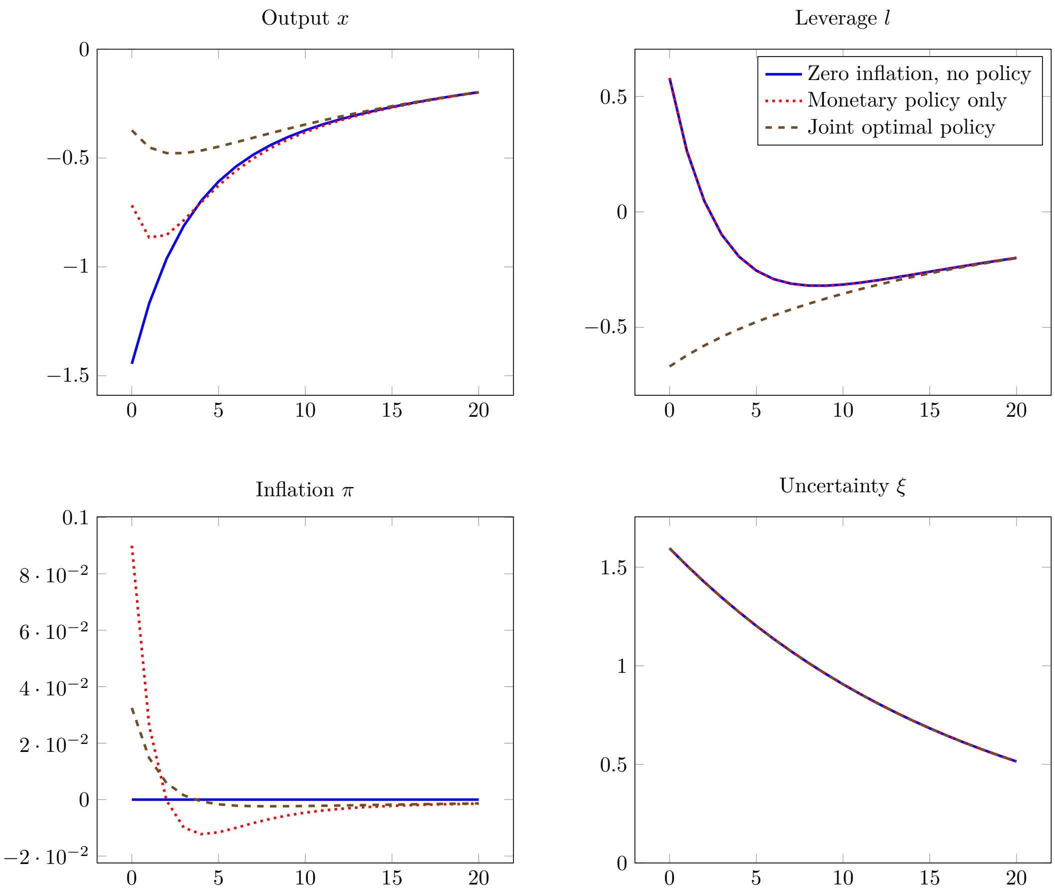

Figure 3: Monetary and prudential responses to a recessionary uncertainty shock.

Figure 3 presents the optimal monetary and joint optimal policy responses to a recessionary uncertainty shock, against the flexible price allocation in the absence of policy. The optimal monetary policy allows inflation to increase in the short run in response to the uncertainty shock, damping the output recession. Under log utility, there is no feedback from monetary policy to leverage. The optimal prudential response to the shock is slightly smaller under optimal monetary policy than under flexible prices (see Figure 2) but ultimately the response of output under optimal monetary and prudential policy is smaller than under prudential policy alone. In the absence of prudential policy, the optimal monetary policy allows for a large increase in inflation upon onset of the shock, and a subsequent period of low inflation to bring the price level back to its target. When prudential policy is optimal, the optimal inflation response to the uncertainty shock is dampened, and the subsequent overshooting of inflation is much smaller in magnitude. Optimal monetary policy still restores the original price level, but with much smaller deviations from zero inflation both at the onset of the shock and in subsequent periods.

3.3 Optimal prudential policy with an interest rate rule

In both the flexible price and optimal monetary policy regimes analysed above, there is no motivation for the prudential authority to respond to technology shocks, where flexible price or optimal monetary policy regimes can effectively manage the demand response to the technology shock, and where under log utility technology shocks do not generate financial instability.

When the aggregate demand response to technology shocks is non-optimal, there is a role for macroprudential policy to support aggregate demand management or reduce the costs of deviations from optimal aggregate demand management. This could be the case under a fixed exchange rate or monetary union regime, when monetary policy follows a simple Taylor-type interest rate rule, or optimises under discretion.[10] We focus on an interest rate rule, but present our result in terms of output and inflation elasticities to shocks, with the intention of facilitating a broader interpretation.

The macroprudential policy trade-offs in response to uncertainty shocks remain similar to the flexible price and optimal monetary policy cases. In order to avoid repetition, we remove uncertainty shocks from the model for this section, allowing technology shocks only.

We assume the policy interest rate follows the simple rule

$$i_t = \phi_\pi \pi_t, \qquad \text{where } \phi_\pi > 1.$$

We then solve the system

$$x_t = \mathbb{E}[x_{t+1}] - (\phi_\pi \pi_t - \mathbb{E}_t[\pi_{t+1}]) - (\zeta - 1)\frac{\psi}{\zeta} l_t \qquad \text{(IS)}$$

$$\pi_t = \beta \mathbb{E}_t[\pi_{t+1}] + \lambda\chi(x_t - a_t) + \lambda\vartheta_l l_t \qquad \text{(PC)}$$

[10]Chen, Kirsanova, and Leith (2017) show that US monetary policymaking is well characterised by an optimising monetary policymaker acting under discretion.

to arrive at a general solution with the form

$$x_t = \eta_{xa} a_t + \eta_{xl} l_t, \tag{3.6}$$

$$\pi_t = \eta_{\pi a} a_t + \eta_{\pi l} l_t, \tag{3.7}$$

where

$$\eta_{\pi a} = -\frac{(1-\rho_a)\lambda\chi}{(1-\beta\rho_a)(1-\rho_a)+(\phi_\pi-\rho_a)\lambda\chi}, \qquad \eta_{xa} = -\left(\frac{\phi_\pi-\rho_a}{1-\rho_a}\right)\eta_{\pi a},$$

$$\eta_{\pi l} = \frac{(1-\phi_1)\lambda\vartheta_l - \frac{(\zeta-1)\psi}{\zeta}\lambda\chi}{(1-\beta\phi_1)(1-\phi_1)+(\phi_\pi-\phi_1)\lambda\chi}, \qquad \eta_{xl} = -\left(\frac{\phi_\pi-\phi_1}{1-\phi_1}\right)\eta_{\pi l} - \frac{(\zeta-1)\psi}{\zeta(1-\phi_1)}.$$

We impose the solution (3.6, 3.7) as a constraint on the macroprudential policymaker. The macroprudential policymaker then solves Programme 3.

Programme 3

$$\min_{\pi,x,l} \mathbb{E}\sum_{t=0}^{\infty}\beta^t\frac{1}{2}\left((1+\omega)\left(\frac{\varepsilon}{\lambda}\pi_t^2 + \chi\left(x_t^2 - 2x_t a_t\right)\right) + \omega\hat{\kappa}_{ll} l_t^2\right)$$

subject to (3.6), (3.7), and

$$\mathbb{E}_t[\Delta l_{t+1}] = -\frac{\psi}{\zeta} l_t.$$

The optimal macroprudential wedge ω can be expressed as follows:

$$\delta_{t+1} = \left(\frac{\phi_2-\phi_1}{\phi_2-\rho_a}\right)\frac{(1+\omega)\left(\frac{\varepsilon}{\lambda}\eta_{\pi l}\eta_{\pi a} + \chi\eta_{xl}(\eta_{xa}-1)\right)}{\omega\hat{\kappa}_{ll} + (1+\omega)\left(\frac{\varepsilon}{\lambda}\eta_{\pi l}^2 + \chi\eta_{xl}^2\right)}\varepsilon_{at+1}.$$

The sign of the prudential policy response to technology shocks is given by the sign of the following expression,

$$\frac{\varepsilon}{\lambda}\underset{-/+}{\eta_{\pi l}}\ \underset{-}{\eta_{\pi a}} + \chi\ \underset{-}{\eta_{xl}}\ \underset{-}{(\eta_{xa}-1)}.$$

Moving from right to left, under the interest rate rule, output increases in response to technology shocks ($\eta_{xa} > 0$) but not by enough to close the welfare relevant output gap ($\eta_{xa} - 1 < 0$). Output falls in response to high leverage ($\eta_{xl} < 0$) and a fall in output in response to high leverage is undesirable from the perspective of aggregate demand management (ie. there is no offsetting -1 attached to η_{xl}, as there is no output-leverage covariance term in the welfare function). The product $\eta_{xl}(\eta_{xa} - 1)$ is therefore positive: the prudential policymaker can reduce the costs of the insufficient output response to technology shocks by increasing ω, generating a countercyclical relationship between leverage and output, and introducing a financial accelerator where there was none before.

This conclusion can change after taking into account the inflation costs of technology shocks. The inflation response to technology shocks is negative $\eta_{\pi a} < 0$, reflecting the insufficient response of output to technology shocks and the resulting counter-cyclical output gap. The inflation response to leverage $\eta_{\pi l}$ can have a positive or negative sign; leverage increases production marginal costs and reduces aggregate demand. If the demand response to leverage shocks is large, then $\eta_{\pi l} < 0$, and the prudential policymaker should introduce financial amplification of technology shocks. Otherwise, and particularly if the welfare costs of fluctuations in inflation are large, then the prudential policymaker should lean against technology shocks, generating a countercyclical path of leverage, and reducing the elasticity of net wealth to output below unity.

Figure 4 presents responses to a recessionary technology shock with and without prudential policy. Under log utility, the divine coincidence holds: optimal monetary policy maintains zero inflation in all periods and optimal prudential policy offers no response to technology shocks. We impose a Taylor-type simple rule with $i_t = \phi_\pi \pi_t$, where $\phi_\pi = 1.7$, a value that allows for a small positive output gap to emerge in response to a recessionary technology shock. Given this interest rate rule, the optimal prudential policy is countercyclical, further damping the output response to the shock relative to the flexible price (optimal policy) path. The countercyclical prudential policy dampens the response of entrepreneurial net wealth to the technology shock, generating a financial dampener, with leverage falling in recessions and rising in expansions. The fall in leverage in response to the recessionary technology shock reduces marginal production costs, both by reducing the shadow monitoring costs of entrepreneurial loans, and by shifting some of the fall in aggregate net wealth to the household sector, generating a wealth effect that increases labour supply. The fall in marginal production costs reduces the inflation

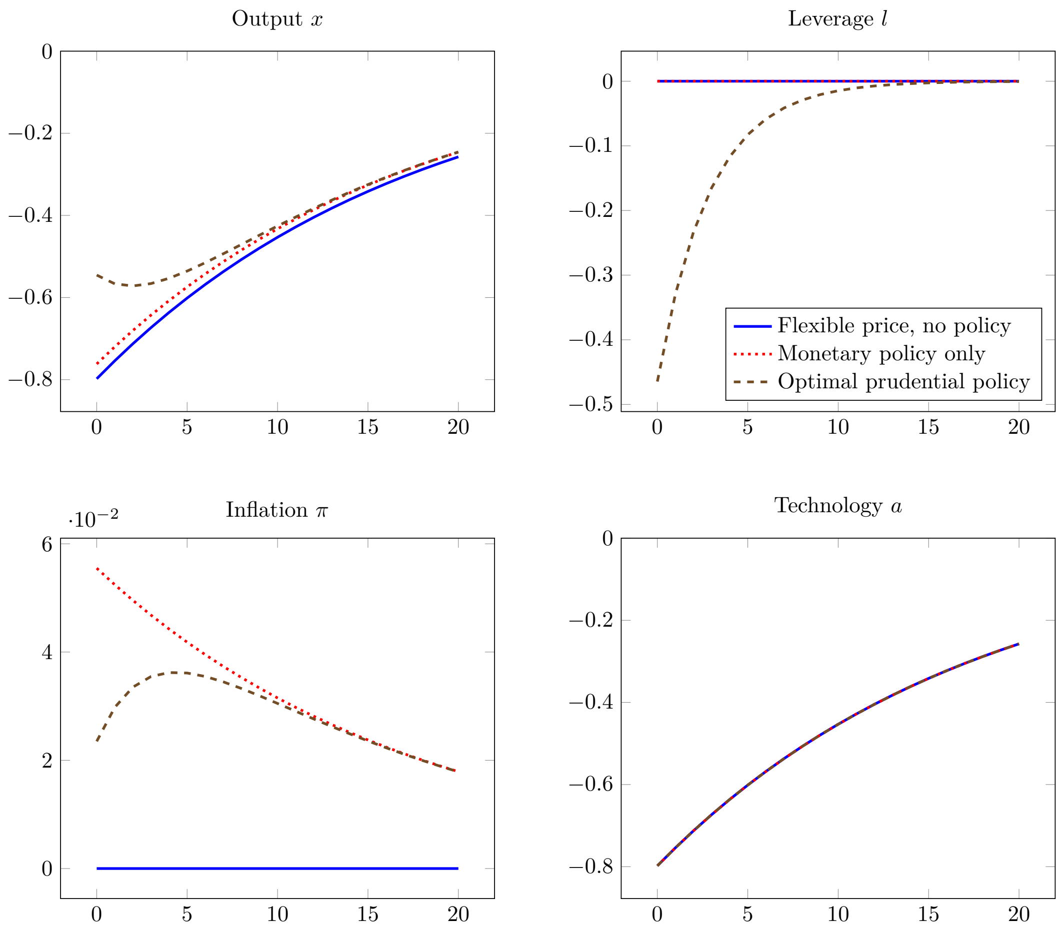

Figure 4: Prudential response to a recessionary technology shock ($\phi_\pi = 1.7$).

response to the shock, and thereby reduces the cost of the departure from optimal monetary policy.

4 Leaning against and cleaning up after financially accelerated technology shocks

In Section 3 we showed that under log utility, the optimal aggregate demand response to technology shocks was to allow real output to rise and fall one-for-one with technology, in line with the canonical New Keynesian model under log utility. When households are less risk tolerant (ie. when their coefficient of relative risk aversion exceeds unity, $\sigma > 1$) any fall in output, even in response to a technology shock, generates a disproportionate fall in net wealth, concentrating risk among the entrepreneurs. This is a consequence of competitive risk sharing in our model—risk averse households seek to protect themselves from business cycles, but market clearing requires that the risk is borne by someone; entrepreneurs are willing to accept that risk at an agreeable price.

The problem is that this concentration of risk on entrepreneurs balance sheets generates a response to recessionary technology shocks that looks like an uncertainty shock, which manifests as an increase in the cost of production. The feedback from technology shocks through to balance sheets generates increased uncertainty that should be prevented or counteracted by policy.

In order to study how macroprudential policy should respond to financially accelerated technology shocks, and how monetary policy could improve upon a strict inflation targeting policy, we simplify our benchmark model in a few important ways.

Assumption 2 *For our analysis in this Section, we make the following simplifying assumptions:*

(i) We remove uncertainty shocks from the model.

(ii) We restrict the monetary policymaker to pursue policies with zero expected future inflation. That is, we define γ as a policy parameter satisfying the following:

$$\mathbb{E}_t[\pi_{t+1}] = 0, \qquad \rightarrow \qquad \pi_t = \lambda\gamma\varepsilon_{at}$$

Assumption 2 (i) removes uncertainty shocks, where the policymaker's problem is not fundamentally altered from the earlier cases studied under log utility in Section 3. Assumption 2 (ii) is very helpful for tractability and is a binding constraint on the monetary policymaker; the results that follow should be interpreted as helping us understand how a deviation from strict inflation targeting can improve outcomes, rather than as characterising optimal policy.

Following Assumption 2, we're left with the following Phillips curve and Leverage curve:

$$(\sigma - 1 + \chi)\, x_t = -(\zeta - 1)l_t + \chi a_t + \gamma\varepsilon_{at}, \tag{4.1}$$

$$\Delta l_t = -\frac{\psi}{\zeta} l_{t-1} - \frac{\sigma - 1}{\zeta} \Delta x_t - \delta \varepsilon_{a,t}, \tag{4.2}$$

where $\chi = \frac{1+\varphi}{1-\alpha}$ and δ is the macroprudential policy parameter.

Consider a monetary policy that allows for a period of high inflation during recessionary technology shocks ($\gamma < 0$). From the equations above, in the current period, this generates a decrease in leverage relative to the counterfactual zero inflation policy. Lower leverage then feeds through to the Phillips curve (4.1), lowering marginal costs and increasing current period output.

Proposition 2 *Consider a monetary policy and a macroprudential policy that generate the same conditional response of output. For both interventions, leverage moves in the opposite direction to output on impact. The macroprudential policy intervention generates a larger (in absolute terms) leverage response on impact than the monetary policy intervention.*

Macroprudential interventions have a relatively large effect on current leverage and monetary policy interventions have a relatively large effect on current output. While both policy interventions have persistent effects on leverage and output, the persistence of monetary policy interventions is dampened, as all else equal higher output today leads to lower output growth tomorrow, increasing future leverage and offsetting the persistent decrease in leverage that would otherwise follow a period of expansionary monetary policy.

Departures from zero inflation incur a welfare cost to the monetary policy authority, which is not incurred as a result of macroprudential policy. However, the effects of monetary policy on output and leverage are different from those of macroprudential policy, and if a departure from zero inflation can reduce the expected welfare costs of volatility in output and leverage, then some departure from zero inflation will be optimal.

Proposition 3 *For generic parameterisations,*

i. both the monetary and macroprudential policy instruments should be used ($\gamma, \delta \neq 0$).

ii. in the absence of one instrument, the other instrument should be countercyclical ($\gamma, \delta < 0$).

Relative strengths of each instrument

The welfare costs of technology shocks in the model, over and above the first-best welfare costs, primarily result from the feedback from output to leverage and back to output—the financial accelerator in the model. Loosely speaking, policymakers seek to reduce this feedback, and the associated volatility of leverage, relative to the flexible price competitive allocation.

Equation 4.3 presents leverage as a function of past shocks. The equation separates the effects of the shock in the absence of policy (shock) from the effects of policy responses (monetary policy, prudential policy). The equation also separates the propagation of the on-impact shock from any anticipated reversal. For example, a one period recessionary shock reduces output growth and increases leverage today, but is followed by a predictable reversal, which increases output growth and reduces leverage in the following period. Similarly, given our assumption that anticipated inflation is zero, any expansionary monetary policy today is followed by a predictable reversal tomorrow.

$$
\begin{aligned}
l_t = &-\left(\frac{\sigma-1}{\sigma-1+\zeta\chi}\right)\ \chi\left(\sum_{\tau=0}^{\infty}\phi^{\tau}\varepsilon_{at-\tau} - (1-\rho_a)\sum_{\tau=1}^{\infty}\sum_{j=1}^{\tau}\phi^{j-1}\rho_a^{\tau-j}\varepsilon_{at-\tau}\right) && \text{(shock)}\\
&-\left(\frac{\sigma-1}{\sigma-1+\zeta\chi}\right)\ \gamma\left(\sum_{\tau=0}^{\infty}\phi^{\tau}\varepsilon_{at-\tau} - \sum_{\tau=1}^{\infty}\phi^{\tau-1}\varepsilon_{at-\tau}\right) && \text{(monetary policy)}\\
&-\zeta\left(\frac{\sigma-1+\chi}{\sigma-1+\zeta\chi}\right)\ \delta\ \sum_{\tau=0}^{\infty}\phi^{\tau}\varepsilon_{at-\tau} && \text{(prudential policy)}
\end{aligned}
$$

Endogenous propagation of shock | Self-reversing of shock / policy response

(4.3)

The monetary and macroprudential instruments differ in the persistence of their effects on the economy. The macroprudential instrument reduces the effect of the technology shock on leverage on impact, but its effect on leverage persists. The monetary policy instrument is largely self-reversing.[11] When technology shocks

[11]Mechanically, this is enforced by our restriction that forecast inflation is zero. In general, monetary policy can offset the leverage effects of persistent technology shocks at the cost of persistent inflation. See Section 5.1 for an example.

are persistent ($\rho_a \to 1$), the dynamics of the leverage response to macroprudential policy matches the dynamics of the leverage response to technology shocks. When technology shocks are not persistent ($\rho_a \to 0$) the dynamics of the leverage response to monetary policy shocks match the dynamics of the leverage response to technology shocks.[12] For this reason, macroprudential policies are relatively better suited to addressing the financial amplification of long term technology shocks and monetary policy is relatively better suited to addressing the financial amplification of short term technology shocks. Figure 5 presents an example to illustrate this result: when shocks are persistent, prudential policy dampens the path of leverage for the duration of the shock, while monetary policy only dampens the effect of the shock on impact, with leverage exceeding the no policy benchmark in subsequent periods. For iid. technology shocks, monetary policy dampens the response of leverage in all periods, while prudential policy causes an overshooting of the response of leverage from period 2 onwards.

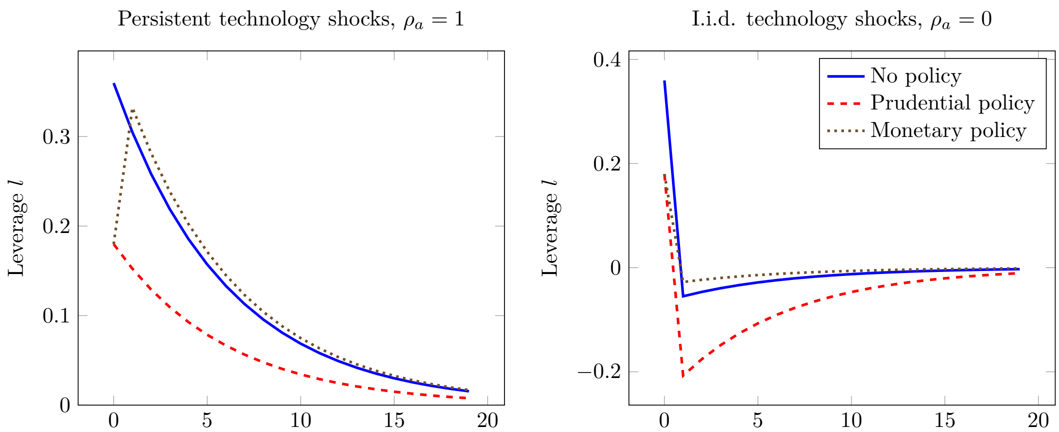

Figure 5: Responses to a unit recessionary technology shock.
Policy parameters γ, δ are chosen such that the period 1 response of leverage to the shock is constant across both policy tools.

Both policy tools share a common cost that their use for countercyclical stabilisation pushes hours worked above the level where their marginal contribution to total output does not compensate for their total sum of disutility and monitoring costs within the period. At the same time, both policy tools reduce the feedback

[12] When verifying this from Equation 4.3, note that it is appropriate to set $\rho_a^0 = 1$ for $\rho_a = 0$.

from output to leverage, reducing the volatility of monitoring costs and thereby increasing welfare. Monetary policy stabilisation suffers the additional cost of inflation, which is not a consequence of prudential stabilisation policy. Nevertheless, monetary policy is still part of the optimal policy mix. Importantly, the two policies have differential effects on leverage and output volatility, with prudential policy having a comparatively larger effect on leverage. Using both policy tools allows the policymaker to better address the marginal welfare costs of fluctuations in output and leverage. Optimal prudential policy alone leaves excess volatility in leverage and output that can be reduced by monetary policy at the second order welfare cost of temporary inflation. The greater the elasticity of substitution between goods ε, the higher the welfare costs of inflation, and comparitively the greater utility of countercyclical prudential policy relative to monetary policy. Similarly, the lower the elasticity of the labour margin (the higher is χ), the more inflation required to offset the output and leverage effects of a given change in technology, worsening the welfare costs of monetary policy stabilisation.

In short, policymakers should use both prudential policy and monetary policy to dampen fluctuations in leverage resulting from technology shocks. Policymakers should put greater reliance on prudential policy when technology shocks are persistent, the labour-output margin is inelastic, and the costs of inflation are high.

5 Financial stability as a monetary policy strategy

In this Section, we consider what monetary policy would be required in order to stabilise ρ, which denotes the equity risk premium and reflects the investment-savings wedge of inefficiency that characterises models of financial amplification of business cycle shocks.

Akinci et al. (2021) denote r^{**} to be the interest rate that stabilises financial frictions, and they study an interest rate policy maintaining r^{**} in a model based on Gertler and Kiyotaki (2010). Our model provides a tractable environment for studying this monetary policy strategy. Our analysis shares some similar insights to Akinci et al. (2021), but we also find a multiplicity of equilibria, where the economy can shift into high or low equilibria in response to temporary monetary policy shocks. This result relies on the fact that in our environment, firms can anticipate future actions from the monetary policy authority, and adjust their risk taking behaviour today in response. Once the economy enters a high inflation, positive output gap equilibrium, financial stability can only be maintained through persistence of the positive output gap. The economy requires a departure from financial stability, for example a recessionary monetary policy shock, to bring inflation down to target and close the output gap.

In order to stabilise the equity risk premium, our measure of financial stress, monetary policy must ensure that leverage moves inversely one-for-one with the uncertainty shock, $l_t = -\xi_t$. To achieve this, the monetary policy authority increases aggregate demand in response to uncertainty shocks, reducing entrepreneurial leverage and thereby negating the response of the equity risk premium to uncertainty shocks. Ultimately, this yields Equations 5.1 and 5.2:

$$\pi_t = \beta \mathbb{E}_t[\pi_{t+1}] + \lambda\left(\sigma + \chi - 1\right) x_t - \lambda \chi a_t + \lambda\left(\theta_\xi - \theta_l - \sigma\omega\right) \xi_t, \tag{5.1}$$

$$\Delta x_t = \left(\frac{\zeta + \sigma\omega\psi}{\sigma - 1}\right) \Delta\xi_t + \varepsilon_{it}. \tag{5.2}$$

where we have added a new iid shock, ε_{it}, which we interpret as a monetary policy shock (the derivations for this Section can be found in Appendix H).

In order to aide interpretation, we will also derive the following expression for the real interest rate:

$$r_t = \left(1 + \frac{\sigma - 1}{\zeta}\right) \mathbb{E}_t[\Delta x_{t+1}] + \frac{\sigma\omega\psi}{\zeta}(1 - \rho_\xi)\xi_t \tag{5.3}$$

where $r_t = i_t - \mathbb{E}_t[\pi_{t+1}]$. The first term on the right hand side of (5.3) captures the expected growth of total consumption across worker households and entrepreneurs. The second term captures the expected change in the distribution of consumption between worker households and entrepreneurs, who have different intertemporal elasticities of consumption and time preferences.

5.1 *Dynamics*

Monetary policy shocks

Consider an expansionary (positive) one-off shock to monetary policy (ε_{it}), starting from the origin, $(\pi_{t-1}, x_{t-1}) = (0, 0)$. From (5.2) we have

$$x_{t+\tau} = \varepsilon_{it} \qquad \forall \tau \geq 0. \tag{5.4}$$

Iterating the Phillips curve (1.2) forward yields

$$\pi_{t+\tau} = \lambda\left(\sigma + \chi - 1\right)\mathbb{E}_{t+\tau}\sum_{j=0}^{\infty}\beta^{j}x_{t+\tau+j} = \frac{\lambda\left(\sigma + \chi - 1\right)}{1-\beta}\varepsilon_{it}. \tag{5.5}$$

The model has a unit eigenvalue associated with eigenvector $[\pi\ x]' = \left[\frac{\lambda(\sigma+\chi-1)}{1-\beta}\ 1\right]'$. This eigenvector is proportional to the economy's response to temporary monetary policy shocks. It follows that after a temporary monetary policy shock, the economy shifts to a new steady state, and does not return to the origin in the absence of a further departure from financial stability.[13] Note that for typical parameter values, $\frac{\lambda(\sigma+\chi-1)}{1-\beta}$ is much larger than 1; equilibria with positive (negative) inflation have very small positive (negative) output gaps.

From 5.3 and 5.4, we can see that in the new steady state the real interest rate is unchanged from it's pre-shock level, $r_{t+\tau} = 0\ \forall \tau \geq 0$. It follows from Equation 5.5 and the Fisher relation that nominal interest rates are permanently higher after a temporary expansionary shock. If the monetary policymaker is unwilling to sacrifice financial stability, then the economy will remain in a high (low) inflation, high (low) nominal interest rate steady state in response to a temporary expansionary (contractionary) shock.

Supply shocks

Now consider a shock to productivity a_t. Under financial stability interest rate policy, productivity shocks are observationally equivalent to New Keynesian cost

[13] Sunspot shocks could also shift the economy between equilibria. In our analysis, we restrict our attention to monetary shocks.

push and/or markup shocks. From (5.2), we can see that output does not respond to the productivity shock,

$$x_{t+\tau} = 0 \quad \forall \tau \geq 0.$$

From the Phillips curve (5.1) we have

$$\pi_t = \beta \mathbb{E}_t[\pi_{t+1}] - \lambda \chi a_t,$$

which we can solve forward to obtain

$$\pi_{t+\tau} = \frac{\lambda \chi}{1 - \beta \rho_a} a_{t+\tau} \quad \forall \tau \geq 0.$$

The real interest rate remains at $r_{t+\tau} = 0, \ \forall \tau \geq 0$ and the nominal interest rate follows the path of inflation $r_{t+\tau} = \pi_{t+\tau}, \ \forall \tau \geq 0$.

In response to a contractionary productivity shocks (and other supply shocks), monetary policy accomodates the shock, allowing inflation to increase temporarily, maintaining output at its steady state level. Inflation returns to its steady state level slowly, at the rate of decay of the shock.

Uncertainty shocks

Similar to supply shocks, uncertainty shocks also increase marginal costs of production. In addition, uncertainty shocks also directly increase the equity risk premium for any given level of leverage or economic output.

Solving the model yields the following responses to uncertainty shocks,

$$\begin{aligned} x_{t+\tau} &= \left(\frac{\zeta + \sigma \omega \psi}{\sigma - 1} \right) \xi_{t+\tau} \quad \forall \tau \geq 0. \\ r_{t+\tau} &= -\left(\frac{\sigma(1+\omega)}{\sigma - 1} \right) (1 - \rho_\xi) \xi_{t+\tau} \quad \forall \tau \geq 0. \\ \pi_{t+\tau} &= \frac{\lambda \mu_\xi}{1 - \beta \rho_\xi} \xi_{t+\tau} \quad \forall \tau \geq 0, \end{aligned} \tag{5.6}$$

where

$$\mu_\xi = \underbrace{(\sigma + \chi - 1)\left(\frac{\zeta + \sigma\omega\psi}{\sigma - 1}\right)}_{\text{output gap}} + \underbrace{(\theta_\xi - \theta_l - \sigma\omega)}_{\text{marginal cost of uncertainty}} .$$

In response to recessionary uncertainty shocks, monetary policy lowers real interest rates in order to generate an output expansion. This is required to raise the value of net worth and reduce leverage, offsetting the impact of the uncertainty shock on financial stability. This expansion results in high inflation, both as a result of the direct contribution of uncertainty to marginal costs, and the increased output gap.

5.2 Macroprudential policy and financial stability interest rate policy

In this section we ask how the outcomes above change in the presence of macroprudential policy. Specifically, can macroprudential policy dampen some of the problems that arise when the monetary policy authority is pursuing a financial stability interest rate policy. It turns out that the answer is sensitive to the shock. In response to interest rate shocks, macroprudential policy cannot eliminate the multiple equilibrium problem; it can reduce the size of the response to interest rate shocks, but that does require damping the passthrough of the monetary shock to real outcomes, which might not be desirable for reasons beyond the scope of this paper. In the presence of uncertainty shocks, any macroprudential policy worsens the outcomes of financial stability interest rate policy, generating a random walk path for output and inflation.

Macroprudential policy can reduce the response of output, inflation and leverage to shocks on impact, but broadly, it doesn't help restore output, inflation and leverage to optimal levels in the wake of shocks. Ultimately, monetary policy authorities must allow departures from financial stability in order to restore optimal allocations, and macroprudential problem cannot eliminate this trade-off.

We write the Leverage curve as follows, where δ_i, δ_ξ represent macroprudential policy responses to the exogeneous shocks:

$$\Delta l_t = -\frac{\psi}{\zeta}(l_{t-1} + \xi_{t-1}) + \frac{\sigma\omega\psi}{\zeta}\Delta\xi_t - \frac{\sigma - 1}{\zeta}\Delta x_t + \delta_i\varepsilon_{it} + \delta_\xi\varepsilon_{\xi t}$$

Equation 5.2 becomes

$$\Delta x_t = \left(\frac{\zeta + \sigma\omega\psi}{\sigma - 1}\right)\Delta\xi_t + \left(1 + \frac{\zeta}{\sigma - 1}\delta_i\right)\varepsilon_{it} + \frac{\zeta}{\sigma - 1}\delta_\xi\varepsilon_{\xi t}.$$

A negative value of δ_i dampens the response of leverage (and ultimately output and inflation) to monetary policy shocks. A negative value of δ_ξ dampens the responses to uncertainty shocks.

Monetary policy shocks

The response of an expansionary one-period monetary shock (ε_{it}), starting from the origin (following Equation 5.4), becomes

$$x_{t+\tau} = \left(1 + \frac{\zeta}{\sigma - 1}\delta_i\right)\varepsilon_{it} \qquad \forall\tau \geq 0.$$

Temporary monetary policy shocks still have a permanent effect on output, and as a consequence, inflation. This response can be dampened by macroprudential policy, with $\delta_i < 0$. However, this would require a macroprudential policy that dampens the response of output and inflation to monetary shocks. In other words, a macroprudential policy that inhibits the transmission mechanism of monetary policy. Such a policy could be undesirable or unsustainable within modern monetary and macroprudential institutional frameworks.

Uncertainty shocks

For uncertainty shocks, we can follow the same steps as for Equation 5.6. The resulting path of output is

$$x_t = \frac{\zeta + \sigma\omega\psi}{\sigma - 1}\xi_t + \delta_\xi\frac{\zeta}{\sigma - 1}\sum_{\tau=0}^{\infty}\varepsilon_{t-\tau}.$$

The path of output has an AR(1) component and a random walk component. Historical uncertainty shocks have both a transitory and a permanent effect on output, and, via the Phillips curve, inflation.

Macroprudential policy can lean against an increase in uncertainty on impact, with $\delta_\xi < 0$. On impact, this will reduce the output response to uncertainty shocks. The problem is that this intervention reduces leverage on impact (or, increases net wealth) and this cannot be reversed by the macroprudential authority, who cannot redistribute in expectation from entrepreneurs to households. The higher net wealth of entrepreneurs becomes persistent if the monetary authority is unwilling to allow a deviation from financial stability at some later date.

6 (Why) are uncertain recessions really inefficient?

Recessions driven by microeconomic uncertainty shocks are important for explaining macroeconomic fluctuations (Arellano, Bai, and Kehoe, 2019; Bloom et al., 2018; Christiano, Motto, and Rostagno, 2014; Di Tella, 2017). Our model shares features with the aforementioned papers that generate a useful role for uncertainty shocks in explaining business cycle outcomes. In particular, uncertainty shocks generate a reduction in aggregate demand, and a labour wedge of inefficiency, reducing the demand for labour below its marginal revenue product.

Under log utility, uncertainty shocks generate a trade-off similar to that posed by New Keynesian cost-push shocks. A monetary policymaker optimising under timeless commitment is willing to tolerate temporary inflation in order to dampen volatility in hours and output. Any deviation of output resulting from uncertainty shocks generates a welfare cost to the monetary policymaker, and their response to those deviations is only dampened by the costs of inflation.

This should be surprising. Uncertainty shocks are shocks to the technology process in the model. Why should the efficient level of hours worked be the same when microeconomic uncertainty is high, relative to when microeconomic uncertainty is low? When microeconomic uncertainty is high, financial contracting and risk sharing is more costly than before. Production is really uncertain; uncertainty shocks are real shocks. If hours worked and production shouldn't fall during an uncertainty shock recession, why do they fall in the competitive equilibrium even in the absence of nominal rigidities?

Static and dynamic leverage constraints

At the start of period t, entrepreneurial leverage can be expressed as

$$l_t = x_t - q_t^e - i_{t-1} + \pi_t, \tag{6.1}$$

where q_t^e is the net wealth brought into period t by the entrepreneur. If we consider a monetary policy that increases output and inflation in the current period, this policy increases leverage for every level of net wealth. Higher leverage means a greater concentration of risk among individual entrepreneurs, and larger wedges of inefficiency in labour and capital markets.

If Equation 6.1 were the constraint faced in period t by the monetary policymaker, then monetary stimulus during uncertainty shocks would be counterproductive. Responding to an increase in uncertainty with an increase in leverage would just amplify the volatility of monitoring costs.[14]

Entrepreneurial net wealth brought into the period q_t^e depends on the anticipated monetary policy response to period t shocks. If a central bank pursues countercylical monetary policy in response to uncertainty shocks, then low interest rates during uncertain recessions will increase the entrepreneurial wealth brought into the period. The dynamic leverage constraint faced by the monetary policymaker is as follows (adapted from Equation 1.3):

$$\Delta l_t = -\frac{\psi}{\zeta}(l_{t-1} + \xi_{t-1}) - \frac{\sigma - 1}{\zeta}\Delta x_t + \frac{\sigma\omega\psi}{\zeta}\Delta\xi_t.$$

In the dynamic setting, stimulative monetary policy increasing output reduces leverage within the period. The sign of the leverage response to aggregate demand stimulus is reversed from the static constraint (6.1). Anticipated monetary stimulus in response to uncertainty shocks can dampen the concentration of risk through an increase in net wealth, reducing the costs of risk bearing and their effects on factor markets.

[14] It can be shown that in a one-period version of the model, the competitive allocation is constrained efficient.

Complements of moral hazard

In the absence of nominal rigidities, our flexible price model is an Arnott-Greenwald-Stiglitz environment (Arnott and Stiglitz, 1986; Greenwald and Stiglitz, 1986). There is an information asymmetry between borrowers and lenders, with competitive anonymous trade in other markets. We have a clear theory of the role of government intervention in these environments: government policy should seek to discourage the complements of moral hazard.

When uncertainty is high, the cost of moral hazard is high. If businesses entered really uncertain business cycles with more equity—more skin in the game—then the cost of really uncertain business cycles would fall. Monetary stimulus during high uncertainty restores equity values, discouraging moral hazard and reducing its effect on employment and output.

Uncertainty increases moral hazard and makes contracting more difficult. This drives wedges between savings and investment and between labour and production. While uncertainty shocks are real shocks to the technological process, they should still be addressed (at least in part) by stimulative monetary policy.

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