Targeting Financial Stability: Macroprudential or Monetary Policy?*

David Aikman † Julia Giese‡ Sujit Kapadia§ Michael McLeay¶

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Abstract

This paper explores monetary-macroprudential policy interactions in a simple, calibrated New Keynesian model incorporating the possibility of a credit boom precipitating a financial crisis and a loss function reflecting financial stability considerations. Deploying the countercyclical capital buffer (CCyB) improves outcomes significantly relative to when interest rates are the only instrument. The instruments are typically substitutes, with monetary policy loosening when the CCyB tightens. We also examine when the instruments are complements and assess how different shocks, the effective lower bound for monetary policy, market-based finance, endogenous crisis severity and a risk-taking channel of monetary policy affect our results.

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†Financial Stability Strategy and Risk, Bank of England (david.aikman@bankofengland.co.uk).

‡Monetary Analysis, Bank of England (julia.giese@bankofengland.co.uk).

§Research Hub, Bank of England (sujit.kapadia@bankofengland.co.uk).

¶Monetary Analysis, Bank of England (michael.mcleay@bankofengland.co.uk).

1. Introduction

The global financial crisis highlighted major deficiencies in macro-financial policy frameworks. Monetary policy before the crisis focused on stabilising inflation; prudential regulation sought to ensure the safety of individual banks. This regime allowed major fault-lines in the financial system to develop unchecked, which materialised to devastating effect in 2007-08. Macroprudential frameworks were a 'missing ingredient' from the pre-crisis regime (Bank of England, 2009), and their development has been one of the major policy responses to the crisis. Under these frameworks, central banks and supervisory authorities globally have new mandates to ensure financial stability, and new macroprudential instruments to enable them to fulfil these mandates (FSB-IMF-BIS, 2011). Some instruments seek to tackle structural, or 'cross-section' risks, while others are concerned with cyclical, or 'time-varying' risks, often associated with credit booms (Borio and Crockett, 2000). The countercyclical capital buffer (CCyB), adopted into the international regulatory framework under Basel III, is an example of the latter.

Given the speed with which macroprudential regimes have been developed, it is perhaps unsurprising that modelling frameworks to guide policy interventions in this sphere are lagging. Without such frameworks, however, a number of key policy strategy and design questions remain unanswered. These questions include: How should we expect the introduction of macroprudential policies to change the volatility of key macro-financial variables? What amplitude should we expect fluctuations in the CCyB to have in order to stabilise risks to banking system stability? And what is the role of monetary policy in leaning against credit booms (Stein, 2013; Kohn, 2015; Svensson, 2016)? Or put more generally, under what conditions are monetary and macroprudential policies likely to be substitutes or complements (IMF, 2013; Shin, 2015)?

In this paper, we attempt to fill this gap in the literature by introducing a simple model for assessing macroprudential policy interventions and their interplay with the conduct of monetary policy. This model provides several sharp insights for the design of macroprudential frameworks. We find that deployment of the CCyB improves outcomes significantly relative to when interest rates are the only instrument, and we explore how macroprudential and monetary policies should be set under different shocks and at the effective lower bound for monetary policy. We also consider whether and when monetary policy should be used to 'lean against the wind', including in the presence of a market-based finance sector and under a strong risk-taking channel of monetary policy. We find that the instruments are typically substitutes: the CCyB should be tightened in a credit boom, with its adverse macroeconomic impact cushioned by loosening monetary policy.

Our model develops Ajello et al. (2016) and is calibrated to fit UK data. There are two-periods; aggregate demand in period one is determined by an 'IS' curve and inflation by a Phillips curve, with the level of credit spreads entering both relationships (in line with Cúrdia and Woodford, 2010). It departs from the New Keynesian tradition by including the possibility that a credit boom will lead to a financial crisis in the second period. The policymaker can lean against the credit boom, and hence stabilise expected future output, by increasing interest rates. But this comes at the cost of lower current activity. In contrast with much of the existing literature, she can also deploy the CCyB.

The CCyB is a macroprudential tool that provides the authorities with a means of increasing bank capital requirements when risks are judged to be building. While many other potential macroprudential tools are available, including sectoral capital requirements and borrower-side restrictions in mortgage markets on loan-to-income or loan-to-value ratios (see Aikman, Haldane and Nelson, 2015), we focus on the CCyB because it is the first tool with a concrete, common implementation framework in all major economies. An analytical framework for the CCyB could therefore serve as a useful case study for other macroprudential instruments.

The CCyB operates via two channels in our model. First, under the assumption that various frictions imply that the Modigliani-Miller theorem fails to hold for banks, higher capital requirements increase banks' overall funding costs. In turn, they pass on these costs to borrowers, raising the cost of bank credit through higher credit spreads, reducing both aggregate demand and aggregate supply. This highlights the potential for the CCyB to be used as a substitute for monetary policy to lean against the financial cycle, reducing volatility in credit growth. But it also illustrates the economic costs that might arise from tightening the CCyB.

While this is the channel that features in most existing analyses of the CCyB (see for instance Angelini, Neri and Panetta, 2014)[1], it contrasts with the mechanism emphasised by the CCyB-setting

[1] An exception is Jiménez et al. (2017).

authorities themselves, who instead focus on the resilience-enhancing role of this tool.[2] Higher bank capital increases the loss-absorbing capacity of the banking system and, with it, the resilience of the financial system. This second channel features front-and-centre in our model: deploying the CCyB boosts the resilience of the banking system and reduces the likelihood of a financial crisis occurring for a given path of credit growth.

The policymaker in our model chooses the level of the interest rate and CCyB simultaneously to minimise a loss function. The loss function is another key novelty of our model. It encompasses the traditional goal of limiting inflation and output volatility, but supplements it by allowing for the incorporation of additional financial stability considerations that manifest as a desire to reduce the crisis probability. This may reflect a desire to avoid direct fiscal or distributional costs from financial crises, and is also consistent with policy-setting in the presence of hysteresis effects from financial crises. This description of preferences provides a better description, we argue, of central banks' post-crisis mandates than the ubiquitous quadratic loss function.

Our key results are as follows. First, we isolate the conditions under which it is appropriate to vary the banking system's capital buffer countercyclically. This is the case if higher capital requirements are associated with adverse aggregate supply effects, which reduce potential output; otherwise, it is appropriate to maintain a permanently high, constant capital buffer over the cycle. Under our preferred model specification, which features some impact on potential supply from higher capital requirements, the policymaker chooses to vary the CCyB quite aggressively: for instance, a CCyB of 5 per cent is required to stabilise the crisis probability when credit growth persistently reaches around 12.5 per cent per year, and in a full stochastic simulation of the model, the standard deviation of the CCyB is around 2.25 percentage points.

Second, we find that deploying the CCyB improves outcomes significantly relative to when the interest rate is the only available tool. This reinforces the rationale for having expanded policy toolkits to include this instrument, and it provides rigorous grounding for the view that macroprudential tools complement monetary policy by reducing macroeconomic tail risks.

[2]The Bank of England describes the primary objective of the CCyB as 'ensur[ing] that the banking system is able to withstand stress without restricting essential services, such as the supply of credit, to the real economy', noting that increases in the CCyB 'may restrain credit growth and mitigate the build-up of risks to banks, but this is not its primary objective and will not usually be the primary objective guiding its setting' (see Bank of England, 2016*b*). The Federal Reserve Board describes the purpose of the CCyB as being 'to increase the resilience of large banking organizations when the Board sees an elevated risk of above-normal losses. Increasing the resilience of large banking organizations should, in turn, improve the resilience of the broader financial system' (see Federal Reserve Board, 2016).

Third, given the tractability of our model, we are able to isolate analytically the conditions when the CCyB and the interest rate are substitutes and when they are complements. We find that the appropriate policy response to a credit boom is governed by two parameter conditions. The first summarises the relative impact of the CCyB on aggregate demand and potential supply via credit spreads. The second summarises the comparative advantage of the CCyB vis-a-vis monetary policy in tackling credit booms, defined as the ratio of the crisis probability and (a weighted average of) the output and inflation elasticities with respect to the CCyB vis-a-vis those same elasticities with respect to the interest rate. Under our benchmark calibration, the comparative advantage in reducing crisis risk lies with the CCyB and the aggregate demand effects of this tool outweigh its impact on potential supply. The instruments are therefore substitutes: faced with a credit boom, it is optimal to tighten the CCyB and to cushion its macroeconomic impact by loosening monetary policy. There are, however, parameter configurations in which the reverse is true, where the instruments are complements, though these cases are less plausible.

In addition to credit booms, we explore optimal policy responses to demand, cost-push and credit spreads shocks, and to combinations of these shocks. The combined credit-aggregate demand shock and the credit spread shock are of particular interest from a financial stability perspective. The former may be thought of as reflecting a positive shock to sentiment, or 'animal spirits', which manifests itself in both the credit and business cycle, e.g. as in the Lawson boom in the United Kingdom in the late 1980s. In response, we find that a joint tightening in macroprudential and monetary policy is warranted. The latter may be interpreted as representing a credit crunch. The instruments are complements in this case too – both the CCyB and interest rates should be cut. But in setting the CCyB, the policymaker faces a tension between supporting current output while at the same time not diminishing future resilience excessively while threats remain – this arguably corresponds to the challenge faced by policymakers in the immediate aftermath of the global financial crisis, especially in Europe.

We explore the robustness of these core results via a set of extensions. First, we find that the CCyB should be used less aggressively when monetary policy is constrained at the effective (zero) lower bound. With monetary policy less able to cushion its macroeconomic impact, the policymaker uses the CCyB less actively and tolerates a higher crisis probability at the margin. Second, we find that the benefits of explicitly coordinating these policy levers are very small: similar economic performance can be achieved by a regime in which the monetary authority targets inflation and output volatility at a 2-3 year horizon and the macroprudential authority focuses on reducing the crisis probability, taking into account the impact of its actions on near-term economic growth.

The next set of extensions shed light on a range of practical policy dimensions and debates in the 'leaning against the wind' debate. In our third extension, we enrich the model by introducing a market-based finance sector that is not subject to the CCyB. This allows us to analyse so-called 'leakages' in which, following a tightening of the CCyB, credit migrates from banks to non-bank institutions and markets outside its scope. Intuitively, this diminishes the effectiveness of the CCyB in reducing the crisis probability. Monetary policy, by contrast, 'gets in all the cracks' (Stein, 2013). We find that the larger the market-based finance sector, the less active CCyB-policy should be in the face of a credit boom.

Fourth, we incorporate a 'risk-taking channel' of monetary policy, whereby banks are incentivised to take on excessive risk when policy rates are set at very low levels and when capital requirements are raised. Intuitively, this militates against the benchmark strategy of relaxing monetary policy to cushion the macroeconomic effects of tackling the credit boom with CCyB hikes. If this channel is particularly strong, we find a qualitative change in the optimal response of monetary policy, which switches to tightening, albeit very moderately, in conjunction with the CCyB in the face of a credit boom.

Fifth, we endogenise the severity of the losses suffered during a financial crisis. We do so in two ways. First, we explore the implications of assuming that a weaker macroeconomy at the onset of a financial crisis leads to more severe crisis losses, as postulated by Svensson (2016). Intuitively, this increases the benefit of monetary policy cushioning any negative aggregate demand effects of deploying the CCyB. Second, we consider how our results are affected if bank capital affects the severity of crises but not their probability, consistent with recent empirical evidence provided by Jordà et al. (2017). The results of this extension are broadly similar to the benchmark model.

Our paper relates to a growing recent literature on the interaction between monetary and macroprudential policies (Smets, 2014). Much of this literature deploys Dynamic Stochastic General Equilibrium (DSGE) models with different types of financial friction to model policy interaction.

One strand of this literature, including Angelini, Neri and Panetta (2014), Angeloni and Faia (2013), Rubio and Carrasco-Gallego (2014) and Tayler and Zilberman (2016) examines optimal simple policy rules. Collard et al. (2017) derive welfare-based loss functions in their set-up to examine jointly Ramsey-optimal policy, as do De Paoli and Paustian (2017), who also analyse non-cooperative equilibria. From a financial stability perspective, these papers focus on the effects of macroprudential and monetary policies on key variables such as leverage and risk taking. They also tend to focus on a specific friction, thus limiting their wider applicability to analysis of a range of trade-offs and practical challenges facing macroprudential policy makers. By contrast, our paper focusses on policy interaction and its effect on the overarching goal of financial system resilience under a broad range of real-world features.

Methodologically, our paper relates to the strand of the literature which develops the ideas of Woodford (2012) and draws on empirical regularities related to financial crises (Drehmann, Borio and Tsatsaronis, 2012; Schularick and Taylor, 2012; Laeven and Valencia, 2013) to carry out cost-benefit analyses of using monetary policy to lean against the wind to reduce the risk of financial crises (Ajello et al., 2016; Svensson, 2016; Filardo and Rungcharoenkitkul, 2016). But all of these contributions focus on monetary policy acting to achieve financial stability in isolation, excluding any role for macroprudential policy.

The paper is organised as follows: Section 2 introduces the model and the calibration; Section 3 discusses the main results from the benchmark model; Section 4 considers the issue of instrument substitutability versus complementarity in the setting of monetary policy and macroprudential policy; Section 5 sets out extensions to the benchmark model; Section 6 concludes. Appendix A contains a detailed derivation of the model's equilibrium conditions and other key equations presented in the main body of the paper, while Appendix B considers a series of robustness exercises.

2. Modelling Macroprudential Policy

In this section, we introduce a parsimonious model for studying the interaction of monetary and macroprudential policies. Our model develops Ajello et al. (2016) and features a New Keynesian core – monetary policy influences aggregate demand via an IS curve, and inflation via a Phillips curve – augmented to include the possibility of a financial crisis, which causes a discontinuous drop in output. The likelihood of such a crisis is increasing in the growth rate of private non-financial sector credit. The central bank can lean against the growth in credit by tightening monetary policy; it can also do so by increasing the required capital buffer for the banking system, which results in higher bank lending spreads and lower economic activity – macroprudential actions therefore affect the objectives of monetary policy and *vice versa*. Higher bank capital also reduces the likelihood of a crisis directly by increasing the loss absorbing capacity of the banking system – its 'resilience'.

2.1. The benchmark model

There are two periods. The first period sees output, inflation, credit growth, loan spreads and the probability of a financial crisis determined by the central bank's policy levers – monetary policy and the countercyclical capital buffer (CCyB) – plus a set of exogenous shocks. Output and inflation outcomes in the second period are exogenous and depend on whether or not a financial crisis occurs.

Aggregate demand and inflation in period 1 are determined by:[3]

$$y_1 = E_1^{ps} y_2 - \sigma(i_1 - E_1^{ps} \pi_2 + \omega s_1) + \xi_1^y \tag{1}$$

$$\pi_1 = E_1^{ps} \pi_2 + \kappa y_1 + \nu s_1 + \xi_1^\pi \tag{2}$$

where y_1 is the gap between output from its target level, π_1 is the deviation of inflation from target, i_1 is the deviation of the central bank nominal interest rate from its steady state level and s_1, as discussed below, is the deviation of the credit spread from its steady state level; ξ_1^y is a demand or consumption preference shock, and ξ_1^π is a cost-push or markup shock. Output in period 2 is denoted by $y_{2,nc}$ in the non-crisis state, but falls to $y_{2,c}$ ($y_{2,c} < y_{2,nc}$) if a crisis occurs – in Section 5, we present an extension to the model in which the severity of the economic contraction in a crisis is endogenously determined. Inflation in period 2 is $\pi_{2,nc}$ and $\pi_{2,c}$ in each respective state.

There are two departures from the canoncial model. First, following Cúrdia and Woodford (2010, 2016) amongst others, we introduce a role for fluctuations in loan spreads, s_1, in driving macroeconomic equilibria. Higher loan spreads push down on aggregate demand via the IS equation

[3]For a detailed presentation of the canonical two-equation New Keynesian model, see Woodford (2003) and Galí (2008).

(1) by increasing the interest rates facing households and firms wishing to borrow for consumption and investment. Higher loan spreads also enter the Phillips curve and act as an endogenous 'cost-push' shock, reducing the economy's productive capacity. This channel could be given a number of structural interpretations. In models where financial frictions exist between households and lenders, such as Cúrdia and Woodford (2010), a cost push effect such as this derives from the impact of higher loan spreads in distorting households' labour supply decisions. Alternatively, in models where firms face binding credit constraints, such as Gertler and Karadi (2011), higher loan spreads lead to capital shallowing, reducing labour productivity. They also increase the cost of financing firms' working capital needs, as in Carlstrom, Fuerst and Paustian (2010).[4]

Second, we assume that the private sector's expectations of period 2 outcomes, denoted E_1^{ps}, are myopic and ignore the possibility that a financial crisis may occur (Gennaioli, Shleifer and Vishny, 2015). In particular, the private sector's period 2 expectations of inflation and output are equal to their (correct) expectation of the outturns conditional on a crisis not occurring.[5]

$$E_1^{ps}\pi_2 = \pi_{2,nc} \tag{3}$$

$$E_1^{ps}y_2 = y_{2,nc} \tag{4}$$

The financial side of our model consists of equations determining real credit demand and supply, and an equation specifiying the probability of a financial crisis:

$$B_1 = \phi_0 + \phi_i i_1 + \phi_s s_1 + \xi_1^B \tag{5}$$

$$s_1 = \psi k_1 + \xi_1^s \tag{6}$$

[4] The same mechanism could also occur when higher loan rates were caused by a higher policy rate, as in the 'cost channel of monetary policy' (Ravenna and Walsh, 2006). We abstract from that possibility here, as it not does not significantly alter our qualitative results.

[5] Ajello et al. (2016) allow the private sector to place a small positive, *exogenous* probability on a crisis occurring. The size of this probability has little qualitative effect on their results, so for simplicity, we assume that the private sector places a zero probability on a crisis occuring.

$$\gamma_1 = \frac{\exp(h_0 + h_B B_1 + h_k k_1)}{1 + \exp(h_0 + h_B B_1 + h_k k_1)} \tag{7}$$

where B_1 is defined as real private non-financial sector credit growth and k_1 is the setting of the CCyB in period 1.

Real credit growth depends negatively ($\phi_s, \phi_i < 0$) on interest rates and credit spreads over the period. A constant term, ϕ_0, captures the steady state rate of credit growth, while ξ_1^B and ξ_1^s are shocks to the quantity and price of credit, which may be correlated with each other and with the demand and supply shocks ξ_1^y and ξ_1^π.

The CCyB influences the likelihood of a financial crisis via two channels. First, all else equal, activating the CCyB directly reduces the probability of a crisis ($h_k < 0$ in (7)). This reflects the resilience benefits of higher bank capital, which increases the loss absorbing capacity of the banking system for a given distribution of shocks. This channel is consistent with the empirical evidence that banks that had more capital on the eve of the global financial crisis had higher survival probabilities (Berger and Bouwman, 2013) and were better able to maintain their supply of loans during the crisis (Carlson, Shan and Warusawitharana, 2013). It is also consistent with theories that emphasise the role of bank capital in incentivising banks to monitor their loans over the cycle (Holmstrom and Tirole, 1997).

Second, activating the CCyB forces banks to rely on a more equity-rich funding structure, which, in turn, pushes up their overall cost of capital. Banks, we assume, are able to pass on some of these increased costs, resulting in higher credit spreads for real economy borrowers and hence lower credit demand in the first period. We capture this relationship in equation (6). The CCyB can influence the risk environment facing banks through this 'leaning' channel: activating the CCyB tempers the build up in credit growth and hence reduces the likelihood of a financial crisis. Note also that the CCyB will have knock-on effects on both aggregate demand and supply via this channel, via the IS curve (1) and Phillips Curve (2).

In the baseline version of our model, monetary policy can also be used to influence the likelihood of a financial crisis by leaning against the build-up of risks associated with credit growth. Higher interest rates reduce credit growth by lowering credit demand and hence influence the risk environment facing the banking system.

2.2. The loss function

We focus in the main on the case of a single policymaker setting interest rates and the CCyB jointly to minimise an overall loss function comprising both monetary and financial stability objectives. This allows us to analyse the normative question of how policy should be set to meet given objectives, free of institutional constraints. It also closely approximates the institutional set-up of the Bank of England: the Monetary Policy and Financial Policy Committees have overlapping objectives, overlapping membership and common information sets.[6] We compare the performance of this set-up to a decentralised Nash game with distinct policy authorities pursuing distinct monetary and financial stability objectives in Section 5.1.

We assign our policymaker a simple loss function that captures the mandates of central banks with responsibility for monetary and financial stability policies. The loss function is an augmented version of that typically used in the monetary policy literature. Overall loss is the sum of period 1 loss and discounted period 2 loss:

$$L = L_1 + \beta L_2 \tag{8}$$

Losses in the first period are quadratic in the deviations of inflation and output from their respective targets, with λ denoting the weight assigned to output deviations relative to those in inflation:

$$L_1 = \frac{1}{2}(\pi_1^2 + \lambda y_1^2) \tag{9}$$

Losses in the second period are given by:

$$L_2 = \frac{1}{2}[(1-\gamma_1)(\pi_{2,nc}^2 + \lambda y_{2,nc}^2) + \gamma_1(\pi_{2,c}^2 + \lambda y_{2,c}^2) + \zeta\gamma_1(\pi_{2,c}^2 + \lambda y_{2,c}^2)] \tag{10}$$

As in period 1, the central bank cares about quadratic deviations of inflation and output from

[6] The objective of the Bank's Monetary Policy Committee is 'to deliver price stability and, subject to this, to support the Government's objectives including those for growth and employment'; the objective of the Financial Policy Committee is 'to protect and enhance the resilience of the UK's financial system and, subject to this, to support the Government's economic objectives including those for growth and employment'. To enhance coordination between monetary and macroprudential policy, the Committees 'are required to have regard to each other's actions'. There is significant cross-membership: both Committees are chaired by the Governor of the Bank, and the Deputy Governors for Monetary Policy, Financial Stability and Markets and Banking are each members of both Committees.

their target levels, as captured by the first two parenthetical terms in inflation and output. But in addition, we introduce a term, parameterised by ζ, which 'over-weights' losses suffered in the event of a financial crisis. When $\zeta > 0$, the policymaker attempts to minimise the probability of a financial crisis to a greater degree than quadratic expected losses alone would imply is optimal. Put differently, the presence of the financial stability objective skews the central banks' objectives towards crisis prevention. The greater is ζ, the more the central bank's objectives are skewed in the direction of crisis avoidance relative to symmetrically stabilising inflation and output. To the best of our knowledge, this formulation of financial stability objectives is novel and is qualitatively distinct from simply increasing the weight attached to future output gaps.

There are three compelling justifications for augmenting the standard loss function in this way. First, in the aftermath of the financial crisis many central banks are mandated to achieve financial stability goals by elected governments on behalf of the public. For example, the Bank of England's Financial Policy Committee has a mandate to 'take action to remove or reduce systemic risks' with a view to 'protect[ing] and enhance[ing] the resilience of the UKs financial system'. As discussed by Peek, Rosengreen and Tootell (2016), such financial stability mandates in part reflect a desire by taxpayers to avoid bearing the bailout costs of future systemic crisis. Financial stability mandates may also reflect a preference to avoid the distributional effects of financial crises, which may be difficult to offset with other policy tools. Second, the potential costs of crises are highly uncertain. Robust control considerations would suggest avoiding the worst case outcome – the output losses associated with a severe crisis in period 2 – rather than targeting expected period 2 output. Third, crises may also generate additional costs that are not captured in our simple two-period framework. For example, if there are hysteresis effects associated with financial crises such that depressed output persists into future periods (Blanchard, Cerutti and Summers, 2015), this would provide an endogenous justification for ζ.[7]

The policy problem facing the central bank therefore is to choose an interest rate and CCyB

[7] As an illustration, suppose there is a third period where output is lower than the steady state level of output if and only if there has been a crisis in period 2, due to hysteretic effects ($y_{3,c} = py_{2,c}$, $y_{3,nc} = 0$). We retain the assumption that a crisis is a one-off event that occurs between periods 1 and 2, or not at all. The parameter p represents the size or persistence of the hysteretic effects. Period 3 loss in the event of a period 2 crisis will then be $L_{3,c} = \frac{1}{2}\lambda p^2 y_{2,c}^2 = p^2 L_{2,c}$, and $L_{3,nc} = 0$ otherwise. These expressions can be substituted into the period 1 loss function:

$$L = \frac{1}{2}(\pi_1^2 + \lambda y_1^2) + (1-\gamma_1)(\beta E_1[L_{2,nc}] + \beta^2 E_1[L_{3,nc}]) + \gamma_1(1+\zeta)(\beta E_1[L_{2,c}] + \beta^2 E_1[L_{3,c}]) \tag{11}$$

rate in period 1 to minimise the loss function (8) subject to the IS curve (1), the Phillips curve (2), the dynamics of credit (5), the equation for credit spreads (6) and the crisis probability function (7), taking as given private sector expectations, E_1^{ps}. Appendix A contains a formal solution to the central bank's problem.

2.3. Calibration

Table 1 reports the parameter values used in the benchmark calibration. We interpret a time period in our model as having a duration of 3 years. This allows us to capture the notion that financial system vulnerabilities build up gradually in response to prolonged credit booms (Aikman, Haldane and Nelson, 2015; Drehmann, Borio and Tsatsaronis, 2012). Moreover, macroprudential policy tools such as the CCyB have longer implementation lags than monetary policy – for example, banks have one year to comply with increases in the CCyB. 3-year time periods therefore capture the interaction between tools in a more meaningful way.

The model's standard macroeconomic parameters, i.e. those that govern the monetary policy transmission mechanism, are calibrated to be consistent the Bank of England's main macroeconomic forecasting model, described in Burgess et al. (2013). This leads us to set $\sigma = 0.6$, which implies that an increase in the annual policy rate of 1 percentage point for a period of 3 years reduces the level of GDP by an average of 0.6% over the period; while $\kappa = 1$ implies that a fall in GDP by 1% over the 3-year period reduces annual inflation by an average of 1 percentage point.[8]

Turning to the transmission mechanism of the CCyB, a 1 percentage point increase in the CCyB is assumed to increase loan spreads by 20 basis points; this calibration is at the top end of the estimates reported in BCBS (2010a). We set ϕ_s, the sensitivity of credit growth to loan spreads, equal to -6, based on Cloyne et al. (2015). This is 4 times as large as the effect of risk-free interest rates on credit growth reported by the same authors. This is reasonable if credit rationing is an important aspect of CCyB transmission, in which case ϕ_s proxies for both the price and non-price channels. This

to give:

$$L = \frac{1}{2}(\pi_1^2 + \lambda y_1^2) + (1-\gamma_1)\beta E_1[L_{2,nc}] + \gamma_1 \beta (1+\overline{\zeta}) E_1[L_{2,c}] \tag{12}$$

where $\overline{\zeta} \equiv \zeta + (1+\zeta)\beta p^2$ is the additional weight placed on avoiding crises, plus an additional term that is an increasing function of the size of p, the hysteresis effects. Even if $\zeta = 0$, so that the policymaker does not exogenously overweight crisis losses, they still endogenously overweight them as long as there is a hysteresis channel ($\overline{\zeta} > 0 \iff p > 0$).

[8] The specific experiment we consider in our calibration exercise is a change in the policy rate in the first quarter of period 1 that is then held constant for three years, implemented via a series of unanticipated monetary policy shocks.

Table 1: *Benchmark parameter values*

Parameter	Description	Parameter	Notes
Standard parameters			
β	Discount Factor	0.97	Matches r*=1%
σ	Interest-rate sensitivity of ouptut	0.6	Burgess et al. (2013)
κ	Slope of the Phillips Curve	1	Burgess et al. (2013)
λ	Weight on output stabilisation	0.05	Standard welfare-based
i^*	Long-run natural nominal rate of interest	3%	Rachel and Smith (2015)
CCyB transmission mechanism			
ψ	Effect of the CCyB on credit spreads	0.2	BCBS (2010a), 1pp CCyB increases loan spread by 20 bps
ω	Effect of spreads on the IS curve	1	Cloyne et al. (2015)
ν	Effect of spreads on the Phillips Curve	0.4	Franklin, Rostom and Thwaites (2015)
Financial conditions equation			
ϕ_0	Average real credit growth	0.21	Sample mean, 1980-2007
ϕ_i	Coefficient on interest rates	-1.5	Cloyne et al. (2015)
ϕ_s	Coefficient on spreads	-6	Cloyne et al. (2015)
Crisis probability equation			
h_0	Constant	-1.7 + 0.11h_k	Estimated using a cross-country dataset
h_B	Sensitivity of crisis probability wrt credit growth, B	5.18	
h_k	Sensitivity of crisis probability wrt to CCyB, k_1	-27.8	
Period 2 parameters			
$y_{2,c}$	Deviation of output from target in crisis state	-0.041	4.1% lost output per year, Close to Brooke et al. (2015)
$\pi_{2,c}$	Deviation of inflation from target in crisis state	0	No effect
$y_{2,nc}$	Deviation of output from target in non-crisis state	0	Steady state
$\pi_{2,nc}$	Deviation of inflation from target in non-crisis state	0	Steady state
ζ	Additional weight on E(crisis cost)	Varied	–
Shocks			
$SD(\xi_1^y)$	Standard deviation of demand shocks	0.0125	Similar to risk premium shock in Burgess et al. (2013)
$SD(\xi_1^\pi)$	Standard deviation of cost-push shocks	0.0011	Similar to markup shock in Burgess et al. (2013)
$SD(\xi_1^B)$	Standard deviation of credit quantity shocks	0.16	Set to match historical data
$SD(\xi_1^s)$	Standard deviation of credit spread shocks	0.006	Matches data on UK banks' CDS premia

Notes. All variables in the model are expressed as deviations from steady state, with the exception of credit growth (B_1, expressed as a growth rate) and the crisis probability (γ_1, expressed as a probability). Other than credit growth (B_1), which is measured as three-year cumulative growth, all variables in the model are measured as annual averages. The CCyB (k_1) is assumed to be set relative to steady state capital ratios of 11%, which are included via the constant term in the equation (h_0).

implies that a 1 percentage point increase in the CCyB reduces three-year cumulative credit growth by only 1.2 percentage points; similar to the median estimate reported in BCBS (2010a), which was a reduction in the level of credit of 1.4% after 18 quarters. We consider alternative calibrations for the impact of the CCyB on the price and quantity of credit in Appendix B.

Regarding the macroeconomic impact of the CCyB, we set the sensitivity of output to spreads equal to that on interest rates, $\omega = 1$, which is broadly consistent with Cloyne et al. (2015).[9] And we calibrate the impact of spreads on inflation, ν, jointly with ϕ_s and κ, using the estimates reported in Franklin, Rostom and Thwaites (2015). This paper finds that each percentage point fall in corporate lending in the recession reduced both capital intensity and UK labour productivity by at least 0.3%.

[9]All else equal, the fact that only a subset of agents in the model are borrowers who will be affected by changes in loan spreads might lead one to expect a smaller effect from changes in such spreads than changes in risk-free rates, the effects of which are more widespread. This would suggest setting $\omega < 1$. However, to the extent loan spreads in our model proxy for other correlated changes in credit supply, for example non-price terms or quantity restrictions, $\omega > 1$ could also be justified.

If we were to assume that falls in lending associated with a higher CCyB had proportionally similar effects on labour productivity, this would imply a value for ν of around 0.6 (0.3 multiplied by κ and $\frac{\phi_s}{3}$ when converted into annual measures). This would imply a relatively large impact of the CCyB on potential supply, and may be an overestimate if one believes that some of fall in UK labour productivity in recent years has been driven by the scale and nature of the financial crisis rather than being a more general phenomenon caused by lower corporate lending *per se*. If the only channel affecting potential output in typical conditions is capital shallowing, then using the capital intensity estimate of 0.3% and the approximate share of capital in production of one-third would imply a fall in labour productivity and potential output of 0.1%. This would instead give an estimate of $\nu = 0.2$. We choose a value midway between these two, allowing for some additional channels from tight credit supply to productivity, over and above its effect on capital accumulation. We consider the sensitivity of our results to this assumption in Appendix B.[10]

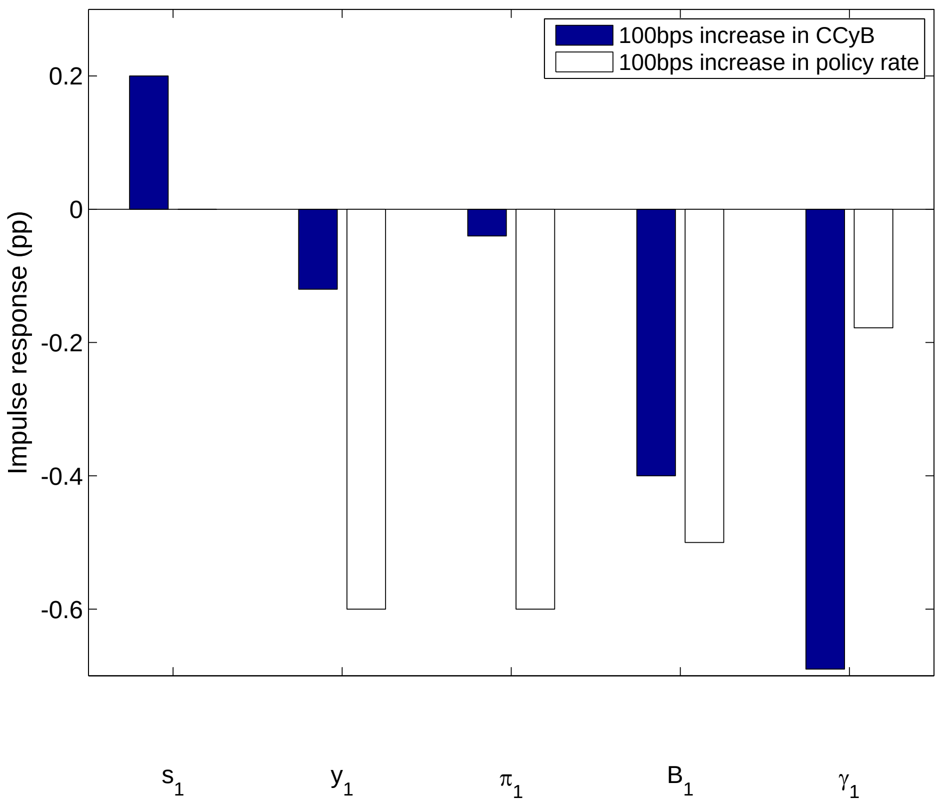
To aide intuition, Figure 1 compares the impact on key model variables of exogenous 100 basis point increases in the CCyB and the monetary policy rate. In short, the monetary policy rate has a materially larger impact on aggregate demand and inflation; the CCyB has a far greater impact on the crisis probability; and these instruments have roughly equal effects on credit growth – although in absolute terms, the dampening effect on credit growth from either instrument is not large.

The parameters governing the crisis probability function are estimated using a cross-country panel dataset; we estimate equation (7) directly using the sample of countries and years for whom both capital and credit data are available, summarised in Table 2.[11] These results are reported in Table 3. Figure 2a illustrates the relationship between credit growth, the CCyB and the crisis probability implied by this equation. Evaluated at a CCyB of 0%, the sample average rate of real credit growth of 7% per year ($\phi_0 = 0.21$ - 21% over three years) and steady state capital ratios of 11%, the annual crisis probability is around 2.5%. The estimated coefficients imply that an increase in credit growth of 1 percentage point to 8% per year would increase the annual probability of a crisis by around 0.4 percentage points, while an increase in the CCyB of 1pp reduces the crisis

[10] Ajello et al. (2016) explore the effects of uncertainty on the setting of monetary policy. While modelling uncertainty is beyond the scope of this paper, an interesting extension would be to examine the effect of uncertainty around the CCyB's impact on supply in particular. Another extension would be to explore whether effects of changes in capital requirements are symmetric through the cycle. It is possible, for example, that an increase in the CCyB during a credit boom has a lower impact on supply as it might constrain the least productive and most risky lending, while a decrease in the CCyB when credit contracts might support productive lending that might otherwise not have happened.

[11] The dataset was constructed by Oliver Bush and Rodrigo Guimarães and we thank them for making it available to us.

Figure 1: *Impacts of 100 basis point increases in the CCyB and monetary policy rate*



Notes. The figure presents the impact on key model variables (the credit spread, s_1, output, y_1, inflation, π_1, credit growth, B_1, and the crisis probability, γ_1) of a 100 basis point exogenous increase in the CCyB (dark blue bars) and the monetary policy rate (white bars).

probability by just over 0.5pp per year to around 2%. [12] In addition, the ratio of the coefficients $\frac{h_k}{h_B}$ implies that an increase in the CCyB of 1 percentage point is sufficient to offset the impact on the crisis probability of just over 5% real credit growth over 3 years, or 1.8% per year. Figure 2b shows the (in-sample) performance of the estimated equation at predicting the probability of a crisis in the UK. The line peaks in 2008 with an estimated annual crisis probability of 12%.

We assume that output in the event of a crisis contracts by an average of around 4% per year, roughly in line with the estimates reported in Brooke et al. (2015) – these estimates incorporate the effect of new resolution regimes in reducing the cost of crises. We assume that inflation remains at target in the crisis state, reflecting the experience internationally in the years following the 2008 crisis (Gilchrist et al., 2017). As we abstract from further shocks, the policymaker is able to achieve

[12]These magnitudes are comparable to the BCBS (2010b) meta-study, where starting at an average crisis probability of around 2%, increasing the TCE/RWA ratio by 1pp (from 9% to 10%) reduces the probability by 0.5pp.

Table 2: *Estimation sample*

Country	Sample period
Australia	1980-2012
Austria	1990-2012
Belgium	1980-1991, 1994-2012
Canada	1980-2012
Denmark	1980-1981, 1986-2012
Finland	1980-1997
France	1980-2012
Germany	1988-2012
Greece	1984-2012
Hong Kong	1981-2012
Ireland	1982-2001
Italy	1982-2012
Japan	1983-2012
Netherlands	1980-2012
Norway	1984-2012
Portugal	1991-2010, 2012
Singapore	1980-2012
South Korea	1980-2012
Spain	1980-1982, 1988-2012
Sweden	1980-2012
Switzerland	1980-2012
United Kingdom	1982-1985, 1988-2012
United States	1985-2012

Table 3: *Logit estmation for the probability of financial crises*

Parameter	Variable	Coefficient
h_0	constant	1.72
		(1.73)
h_B	$\sum_{i=1}^{3} L_i.\Delta\ \log Cred_t$	5.18**
		(2.38)
h_k	$L.Cap_t$	-60.6**
		(28.9)
Pseudo R^2	0.0845	
Pseudolikelihood	-73.7	
χ^2	49.6***	
p-value	0.0002	
AUROC	0.718***	
	(0.0587)	
Observations	423	

*** Significant at the 1% level.

** Significant at the 5% level.

* Significant at the 10% level.

Notes. Robust standard errors are shown in parenthesis. Regression includes dummies for country fixed effects. These are set to zero for the UK to identify the constant parameter h_0. $\Delta\log Cred_t$ is the annual growth rate of real lending. Cap_t is the ratio of tangible common equity to total assets. We obtain the parameter h_k by translating the estimated coefficient into a comparable measure of the effect of changing *risk-weighted* capital requirements. We do this by dividing by 2.19, based on the estimation for Euro-area banks reported in BCBS (2010b, Table A5.1).

zero output and inflation gaps in period 2 if a crisis does not occur.

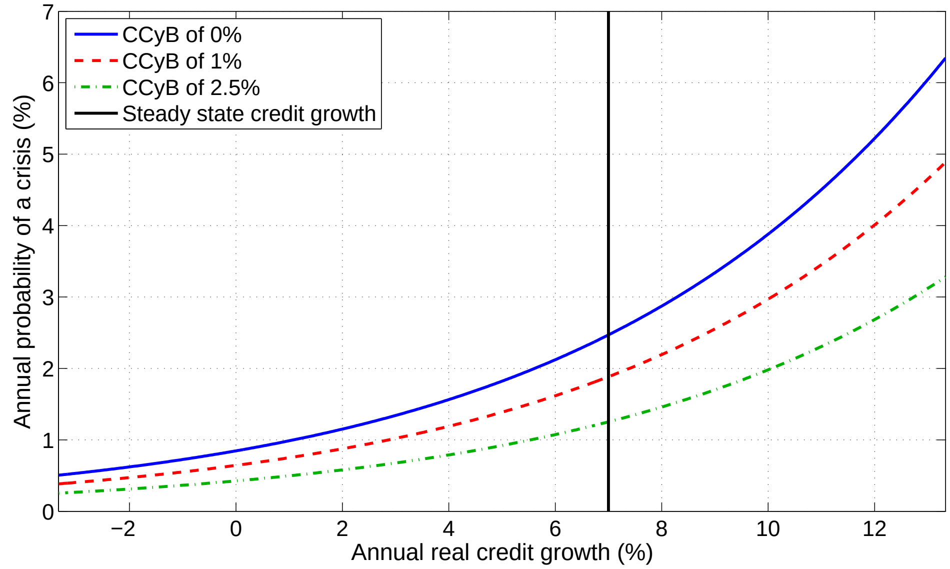
Finally, the standard deviations of the demand and inflation shocks are calibrated to be close to the estimated standard deviations of similar shocks in Burgess et al. (2013) – a risk premium shock for demand, and a combination of two markup shocks for inflation. The standard deviation of the credit quantity shock is set to be broadly consistent with the standard deviation of credit in the UK historical data; while the loan spread shock is set to match the standard deviation of average UK bank CDS spreads over the crisis period.

3. Main Results

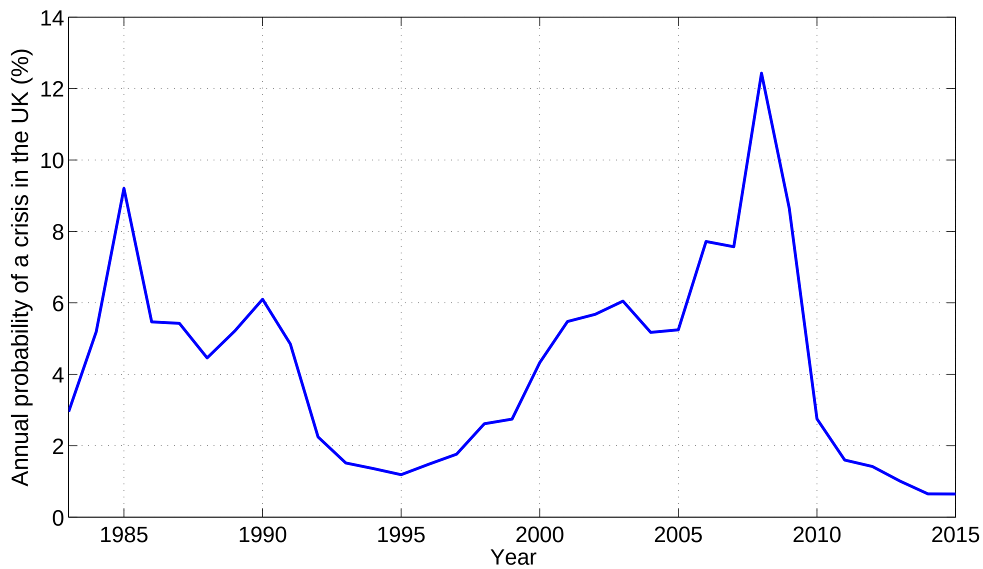
We begin this section by examining the trade-offs facing a central bank that has only access to a traditional monetary policy instrument. We then show that, relative to this benchmark, welfare is

Figure 2: *Crisis probability function*

(a) *Crisis probability and credit growth for different levels of the CCyB*



(b) *Time series of model-implied crisis probability for the United Kingdom*



Notes. The upper panel plots the relationship between the financial crisis probability and credit growth in equation (7) under the benchmark calibration for alternative values of the CCyB. The lower panel plots a time series of the model-implied crisis probability, obtained by evaluating equation (7) for realised values of credit growth and banking system leverage for the United Kingdom.

higher when this toolkit is augmented to introduce active use of the CCyB.

3.1. Monetary policy-only case

In the benchmark monetary policy-only economy, the CCyB is fixed at 0 per cent and spreads are exogenous. In this case, the first-order condition governing the central bank's interest rate policy in period 1 is (see Appendix A):

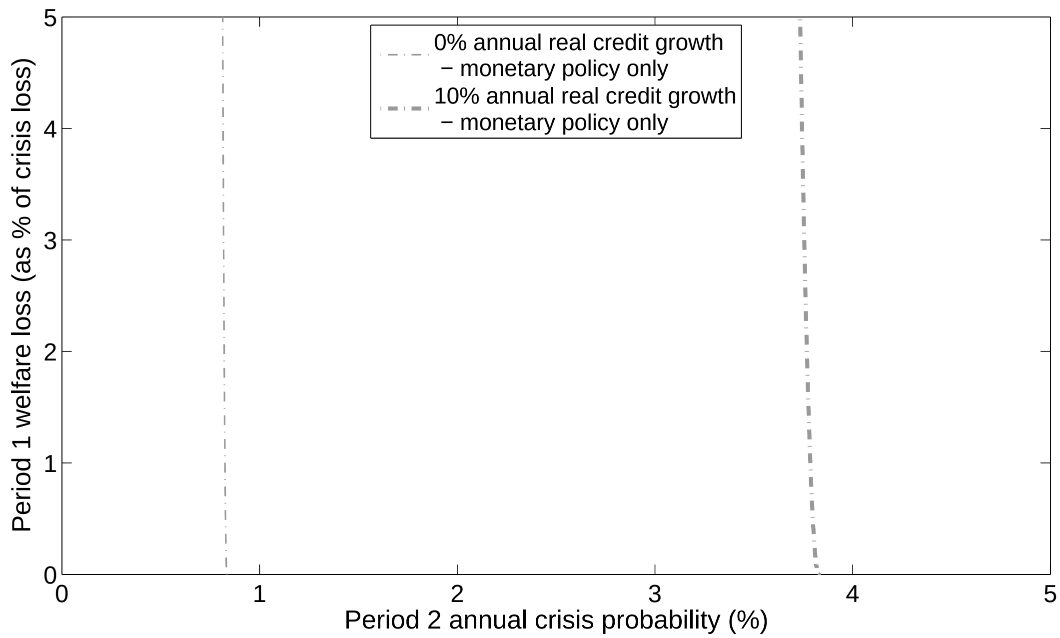
$$\sigma(\kappa\pi_1 + \lambda y_1) = \frac{\partial \gamma_1}{\partial i_1}\frac{\partial L}{\partial \gamma_1} \tag{13}$$

where $\frac{\partial \gamma_1}{\partial i_1}$ is the derivative of the crisis probability with respect to interest rates, and $\frac{\partial L}{\partial \gamma_1} = -\beta(\pi^2_{2,nc} + \lambda y^2_{2,nc}) + \beta(1+\zeta)(\pi^2_{2,c} + \lambda y^2_{2,c})$ is the policymaker's marginal expected discounted loss from a crisis, which is a function of the severity of the crisis state and the importance of the financial stability objective in the central bank's objective function.

This is an augmented version of the standard condition for optimal monetary policy, $\lambda y_1 = -\kappa\pi_1$ (Clarida, Galí and Gertler, 1999). Intuitively, it collapses to the standard condition when either the probability of a financial crisis γ_1 is insensitive to credit growth, or when credit growth is insensitive to interest rates, $\phi_i = 0$. Outside of these special cases, monetary policy must balance two trade-offs: first, the standard intra-temporal trade-off between stabilising inflation and output in period 1 in the presence of cost-push shocks; second, an inter-temporal trade-off between stabilising output and inflation in period 1 and stabilising the probability of a financial crisis, which, if it occurs, would depress output in period 2.

Figure 3 presents this intertemporal trade off. Each curve traces out the combination of inflation, output and the crisis probability that minimises the policymaker's loss function for different levels of ζ, the relative weight placed on maintaining financial stability in the loss function. Points to the northeast of each curve are strictly inferior, while points to the southwest are infeasible. The y-axis shows the period 1 loss from using monetary policy to lean against the credit boom: raising interest rates results in an undershoot of the period 1 inflation and output targets *for certain*. The x-axis shows the financial stability benefit of doing so: lower credit growth reduces the crisis probability, so increases period 2 output *in expectation*. The frontier is extremely steep, indicating that the financial stability benefit of leaning against the credit boom with higher interest rates is limited relative to the shorter-term inflation and output costs of doing so. A credit boom shifts the intertemporal frontier

Figure 3: *Monetary and financial stability trade-off with monetary policy only*



Notes. The figure presents the trade-off facing a central bank with access to monetary policy tools alone between period 1 losses resulting from inflation and output deviations from their respective targets and the probability of a financial crisis occurring in period 2. The curve is obtained by varying ζ in equation (13). The thin dash-dotted line shows the trade-off at 0% real credit growth; the thick dash-dotted line shows the trade-off at 10% per year growth in real credit for three years. The curves are drawn assuming that cost push shocks, ξ_1^{π}, are zero.

to the right, worsening the trade-off faced by the policymaker.

3.2. Two instruments: introducing the CCyB

We now turn to the case where the policymaker has two tools at her disposal: conventional monetary policy and the CCyB. As we show in Appendix A, there are now two first-order conditions that govern optimal policy; in particular, equation (13) is now augmented by the condition:

$$\lambda y_1(-\frac{\nu\psi}{\kappa}) = (\frac{\partial\gamma_1}{\partial k_1} + \frac{\partial\gamma_1}{\partial i_1}(\frac{\nu\psi}{\kappa\sigma} - \omega\psi))(-\frac{\partial L}{\partial\gamma_1}) \tag{14}$$

This equation governs how the policymaker should trade-off the marginal costs of increasing the CCyB, in terms of foregone current output (shown on the left-hand side), with the marginal benefits it provides of a reduced likelihood of a financial crisis in future (shown on the right-hand side). In evaluating marginal benefits, the policymaker takes into account both the direct effects of the

CCyB on the crisis probability via the boost to resilience it provides and its indirect effect in cooling credit growth; both channels are incorporated in the partial derivative $\frac{\partial \gamma_1}{\partial k_1}$. She also takes into account the additional impact that results from the endogenous reaction of monetary policy to the macroeconomic footprint left by the CCyB, summarised by the term $\frac{\partial \gamma_1}{\partial i_1}(\frac{\nu\psi}{\kappa\sigma} - \omega\psi)$. If the aggregate demand effects of the CCyB dominate its aggregate supply effects, this term will be negative and monetary policy will loosen to cushion the effect of a tightening in the CCyB, offsetting somewhat the gains from running countercyclical macroprudential policy.[13]

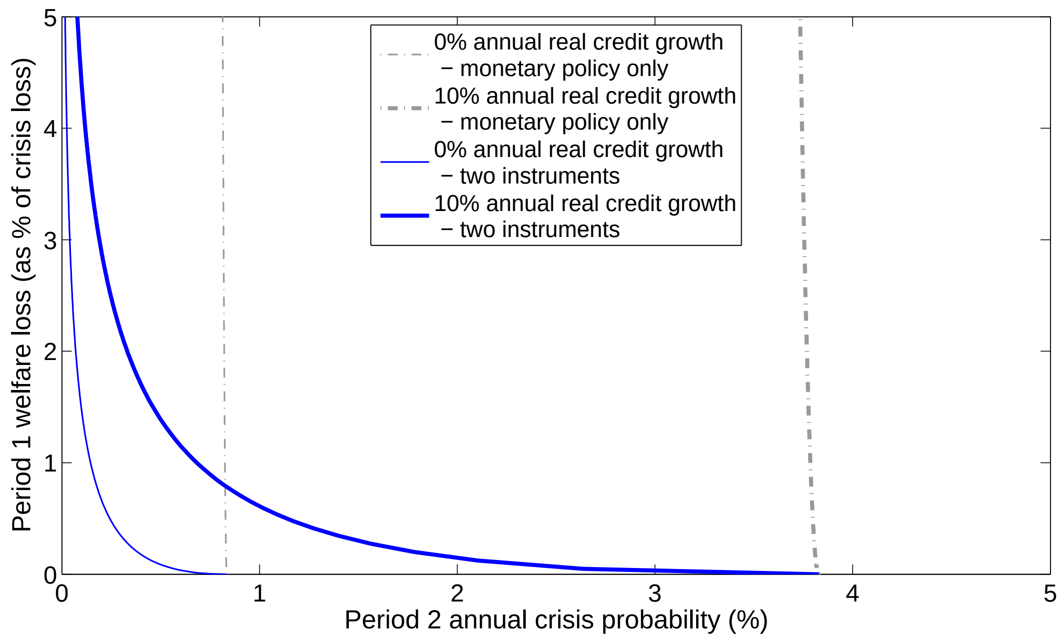
The blue solid lines in Figure 4a present the intertemporal trade off facing a policymaker with access to both monetary policy and the CCyB. Aside from the limiting case where the crisis probability approaches zero, the trade-off frontier is significantly flatter than when monetary policy is the only policy lever. The curve is also shifted to the left, indicating that a Pareto improvement is possible: significant financial stability benefits can be obtained relative to the monetary policy-only case without any macroeconomic cost. This result obtains because the CCyB can be directed at stabilising the crisis probability by matching the resilience of the banking sytem to the risk level it faces, while monetary policy can cushion the short-term macroeconomic cost of countercyclical macroprudential policy by focusing on its traditional tasks of inflation and output stabilisation. This, of course, is Tinbergen's famous result: to achieve n independent targets there must be at least n effective instruments.

Although outcomes are unambiguously superior to the monetary policy-only case, in general a trade-off between monetary and financial stability objectives will continue to exist and attempts to reduce the crisis probability will have inflation and output costs in the first period. This is because active variation in capital requirements makes intermediation more costly, which impairs the ability of the financial system to transform savings into investment, reducing the level of potential output.

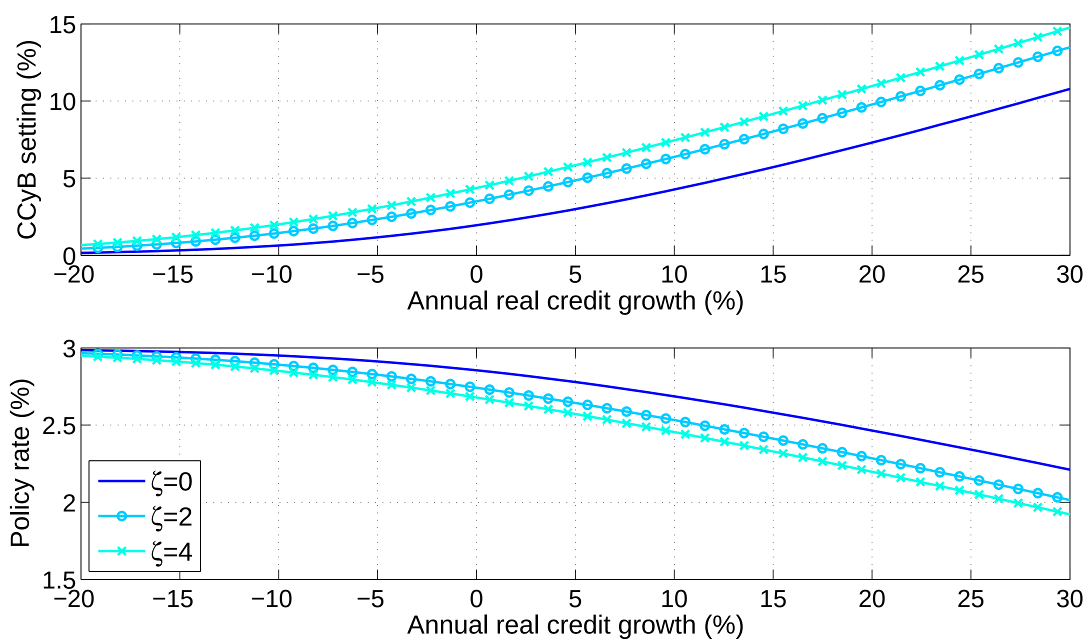
If there were no detrimental supply-side effects of using the CCyB – that is, if we set $\nu = 0$ – and moreover, if there were no effective lower bound on interest rates (we consider the implications of a binding lower bound in Section 5), it would be optimal to set the CCyB at a very high level permanently and to use monetary policy to offset the negative effects of higher loan spreads on

[13]Since using the CCyB introduces a trade-off, the policymaker will *choose* to reduce the interest rate below the natural rate to achieve the optimal balance between output and inflation losses. But since an optimising policymaker must be indifferent at the margin between additional output losses or inflation losses, the net marginal benefits are the same as if policy tracks the natural rate.

Figure 4: *Monetary and financial stability trade-off with monetary policy and the CCyB*



(a) *The intertemporal trade-off*



(b) *CCyB and interest rate policy functions as a function of annual real credit growth*

Notes. For an explanation of the upper panel see the note to Figure 3. The blue solid lines in this panel plot the trade-off when both monetary policy and the CCyB are available tools. The lower panel presents the optimal setting of the CCyB and the nominal interest rate for varying levels of annual real credit growth. The solid line, circles and crosses show the optimal setting, respectively, for the cases where $\zeta = 0$, $\zeta = 2$ and $\zeta = 4$.

aggregate demand. In our simple framework, this would reduce the probability of a crisis to an arbitrarily low level, reducing the policy problem to the simpler one of achieving the appropriate balance between output and inflation stabilisation. Outside of this special case, there is always a trade-off between monetary and financial stability objectives for the policymaker to manage.

Figure 4b illustrates the adjustments in the CCyB and the interest rate required to implement optimal policy. It shows the settings required under our benchmark calibration for varying levels of credit growth and different settings for ζ, the policymaker's preference parameter for avoiding the costs associated with financial crises. As credit growth increases, the policymaker chooses to increase the CCyB, boosting the resilience of the banking system. At the same time, she reduces interest rates to cushion some of the reduction in demand brought about by applying the CCyB. The interest rate and the CCyB therefore exhibit instrument substitutability under the benchmark calibration.

To provide a sense of the quantitative variation in these instruments, when $\zeta = 0$, the CCyB response required to optimally stabilise the crisis probability in the face of annual real credit growth of 12.5 per cent per year is around 5 per cent. These lines corresponds to the case where the policymaker cares only about quadratic deviations of inflation and output from target. The adjustment in monetary policy required to cushion the macroeconomic impact of this level of the CCyB is strikingly modest, with the policy rate falling by 35 basis points. This reflects the relatively benign impact of the CCyB on lending spreads in the calibration. When the policymaker places a higher weight on financial stability considerations, both instruments are used more actively. With $\zeta = 2$, a CCyB response of 5 per cent is required for annual credit growth of only 5 per cent per year.

Table 4 reports key summary statistics from the model under both the monetary policy-only and monetary policy-plus-active-CCyB regimes. As a benchmark for comparison, we also report these statistics under a myopic monetary policy regime, which is focused solely on inflation and output stabilisation in period 1, ignoring the possibility of a crisis occurring in period 2. We consider the performance of these regimes both in the case where credit shocks, ξ_1^B, are the sole disturbance to the economy, shown in rows (i)-(vi), and in a full stochastic simulation of the model using the variance-covariance matrix of shocks reported in Table 1, shown in rows (vii)-(xii). For each case, we present one set of results for $\zeta = 0$, and one for $\zeta = 2$.[14]

Table 4: *Macroeconomic outcomes under different policy regimes and model variants*

Case	SD(y_1)	SD(π_1)	SD(B_1)	median(γ_1)	SD(i_1)	SD(k_1)	$E(L)$
Simulation using credit shocks only							
$\zeta = 0$:							
(i) Myopic policy regime	0	0	5.8	2.39	0	-	3.62
(ii) Monetary policy-only regime	0.002	0.002	5.8	2.39	0.003	-	3.62
(iii) CCyB regime	0.11	0.005	5.3	0.77	0.11	1.45	1.37
$\zeta = 2$:							
(iv) Myopic policy regime	0	0	5.8	2.39	0	-	10.86
(v) Monetary policy-only regime	0.005	0.005	5.8	2.39	0.008	-	10.86
(vi) CCyB regime	0.13	0.006	5.2	0.40	0.13	1.74	2.48
Simulation using all shocks							
$\zeta = 0$:							
(vii) Myopic policy regime	0.25	0.013	5.9	2.57	2.03	-	4.10
(viii) Monetary policy-only regime	0.25	0.013	5.9	2.57	2.03	-	4.09
(ix) CCyB regime	0.16	0.008	5.4	0.75	2.05	2.28	1.53
$\zeta = 2$:							
(x) Myopic policy regime	0.25	0.013	5.9	2.57	2.03	-	11.51
(xi) Monetary policy-only regime	0.25	0.014	5.9	2.57	2.03	-	11.50
(xii) CCyB regime	0.20	0.010	5.3	0.40	2.1	2.23	2.66

Notes. The table presents results obtained by running a stochastic simulation of the model. The standard deviations of output (y_1), inflation (π_1), credit growth (B_1), the interest rate (i_1) and the CCyB (k_1) are reported in terms of annual percentage points; the median crisis probability (γ_1) is reported as an annual percentage rate; expected losses are reported as a per cent of losses incurred in the event of a financial crisis occuring in period 2. The results are reported for two alternative values of ζ, the relative weight placed on stabilising the crisis probability in the loss function. For both sets of results, expected losses are shown as a per cent of losses incurred in the event of a crisis assuming that $\zeta = 0$, $L_{2,c}|\zeta = 0$.

Consider first the case where credit shocks are the only disturbance to the economy. In this case, the myopic monetary policy regime reported in rows (i) and (iv) generates zero volatilty in output, inflation and the nominal interest rate – this reflects the simple structure of our model, in which

[14] For each line of the simulations with only credit shocks, 200 draws are made from a mean zero normal distribution with the standard deviation of credit shocks in Table 1. The optimal settings of each instrument are calculated for each draw by finding the solution to the pair of non-linear equations (13) and (14). For the full stochastic simulation, 200 sets of four independent draws are made according to the standard deviations given in Table 1, giving 200 sets of draws for the four shocks. For simulations with only one instrument, the value of the other instrument is set to zero in the solution in place of the first order condition for that instrument.

credit growth has no direct impact on output or inflation. The standard deviation of annual credit growth in this economy is 5.8 percentage points, and the median annual crisis probability across the simulations is 2.39 per cent. This results in expected losses of 3.62 per cent. It is striking how similar these results are to the monetary policy-only regime, reported in rows (ii) and (v). Evidently, lengthening the horizon of monetary policy in the benchmark model carries little benefit relative to a myopic regime – this reflects the high costs of leaning against the wind with monetary policy in our baseline calibration. By contrast, expected losses are reduced significantly (by almost two-thirds when $\zeta = 0$ and over three-quarters when $\zeta = 2$) when the CCyB is available as an additional policy lever, as shown in rows (iii) and (vi) – this is despite its use generating a small increase in the standard deviations of inflation and output, and only achieving a modest reduction in that of credit growth. The welfare benefits instead derive from the large reduction in the median crisis probability, which falls from 2.39 per cent to 0.77 per cent and 0.40 per cent in the $\zeta = 0$ and $\zeta = 2$ cases, respectively. This in the main reflects the impact of the CCyB in bolstering the resilience of the banking system rather than its impact on the credit cycle.

These results are qualitatively unchanged in the full stochastic simulation of the model reported in rows (vii) to (xii). The presence of cost-push shocks in this case generates an irreducible trade-off between inflation and output stabilisation in all policy regimes, and the volatility of inflation and output increase accordingly. While active use of the CCyB once again achieves a significant reduction in the crisis probability, from 2.57 per cent to 0.75 per cent and 0.40 per cent in the ζ equals 0 and 2 cases, respectively, it now also *reduces* the standard deviations of output and inflation. The reason for this perhaps surprising result is that the CCyB alters the trade-off between inflation and output, and so is able to assist monetary policy in partially offsetting cost-push and spread shocks. This potential for macroprudential policy to offset trade-off inducing markup shocks has previously been highlighted by De Paoli and Paustian (2017).

The adjustments in the CCyB required to achieve these benefits are quite large: its standard deviation in the credit shocks-only case ranges from 1.45 to 1.74 percentage points, depending on the value of ζ; this rises to around 2.25 percentage points in the full simulation. This raises a potential concern about the calibration of CCyB regimes in some jurisdictions, which set the maximum permissible CCyB rate at 2.5 per cent.

4. When are These Policies Complements vs. Substitutes?

As we have seen, under the benchmark calibration the CCyB and the interest rate are substitutes for tackling a credit boom: the policymaker finds it optimal to tighten the CCyB and to reduce interest rates to cushion the resulting macroeconomic impact. But how general is this result? And how do the instruments respond to other shocks? We address these questions in this section of the paper.

4.1. Responses to credit booms

There are three mutually exclusive cases for policy interaction in our benchmark model. First, as in the benchmark calibration discussed so far, policies can be *instrument substitutes*, whereby monetary policy is loosened in response to a tightening in the CCyB. Second, policies can be *instrument complements*, whereby the policymaker chooses to tighten the CCyB and to accompany this with a hike in interest rates. And third, policies can be instrument substitutes, but the *assignment of instruments is reversed* such that the CCyB is used to target inflation and output and interest rates are directed towards reducing the probability of financial crises. We summarise these cases in Table 5.

Table 5: *Optimal policy in response to a credit boom (Shock to: ξ_1^B)*

Case	Δk_1	Δi_1	Parameter restriction	Intuition
Instrument complements	$+$	$+$	$\frac{\kappa^2}{\kappa^2+\bar{\lambda}}\frac{\nu\psi}{\kappa} > \sigma\omega\psi$	The impact of the CCyB on potential output sufficiently exceeds its impact on demand
Instrument substitutes	$+$	$-$	$\frac{\nu\psi}{\kappa}\frac{\kappa^2}{\kappa^2+\bar{\lambda}} < \sigma\omega\psi$, $\frac{\frac{\partial\gamma_1}{\partial k_1}}{\frac{\partial\gamma_1}{\partial i_1}}\frac{\sigma}{(\sigma\omega\psi+\frac{\kappa^2}{\lambda+\kappa^2}\frac{\nu\psi}{\kappa})} > 1$	The impact of the CCyB on potential output does not sufficiently exceed its impact on demand, and the CCyB has a comparative advantage for reducing crisis probability
Instrument substitutes and sign switches	$-$	$+$	$\frac{\frac{\partial\gamma_1}{\partial k_1}}{\frac{\partial\gamma_1}{\partial i_1}}\frac{\sigma}{(\sigma\omega\psi+\frac{\kappa^2}{\lambda+\kappa^2}\frac{\nu\psi}{\kappa})} > 1$	The impact of the CCyB on potential output does not sufficiently exceed its impact on demand, and monetary policy has a comparative advantage for managing the crisis probability

Notes. The conditions in the table are derived in Appendix A. The parameter $\bar{\lambda}$, also defined in Appendix A, is a function of the policymaker's preference parameter, λ, which governs the policymaker's optimal 'split' of cost-push shocks between output and inflation. It is adjusted to take account of the fact that the optimal split also depends on financial stability considerations. It can range between zero and λ, but in our benchmark calibration is very close to λ.

The determinant of whether monetary policy and macroprudential policy are instrument substitutes or complements is the relative (weighted) impact of the CCyB on potential output and aggregate demand. The impact of the CCyB on aggregate demand in the model operates via its effect on lending spreads, and is given by $\sigma\omega\psi$. Its impact on potential output is given by $\frac{\nu\psi}{\kappa}$. In our benchmark calibration, the impact of the CCyB on demand exceeds that on potential supply. But if, and only if, $\frac{\nu\psi}{\kappa}\frac{\kappa^2}{\kappa^2+\lambda} > \sigma\omega\psi$, then the policies are instrument complements. Intuitively, if the CCyB has a greater impact on potential supply than on aggregate demand, then its use will tend to push up on inflation, necessitating a tightening in monetary policy. This in turn will also lower the crisis probability somewhat, reducing the required CCyB tightening. As the impact of the CCyB on aggregate demand increases, or as the relative weight on inflation stabilisation in the loss function falls, these policies switch to acting as instrument substitutes. Note that this result hinges on the relative magnitude of demand and supply effects: if a CCyB tightening were to *increase* aggregate demand rather than reduce it as in our benchmark calibration, it would also be optimal to tighten monetary policy even if the potential supply effects of the CCyB were small.

Turning now to the issue of instrument assignment, the policymaker in our model sets monetary and macroprudential policies in a coordinated fashion to minimise an overall loss function comprising both monetary and financial stability objectives. She does not, therefore, have an in-built preference for using one instrument over the other for achieving specific goals. Instead, the decision of how policy instruments are adjusted in response to different shocks depends on their comparative advantage.

We define the comparative advantage of the CCyB at achieving financial stability goals by X:

$$\begin{aligned} X &\equiv \frac{\frac{\partial\gamma_1}{\partial k_1}}{\frac{\partial\gamma_1}{\partial i_1}}\frac{(\lambda\frac{\partial y_1}{\partial i_1}+\kappa\frac{\partial\pi_1}{\partial i_1})}{(\lambda\frac{\partial y_1}{\partial k_1}+\kappa\frac{\partial\pi_1}{\partial k_1})}-1 \\ &= \frac{\frac{\partial\gamma_1}{\partial k_1}}{\frac{\partial\gamma_1}{\partial i_1}}\frac{\sigma}{(\sigma\omega\psi+\frac{\kappa^2}{\lambda+\kappa^2}\frac{\nu\psi}{\kappa})}-1 \end{aligned} \tag{15}$$

where X is the ratio of the crisis probability and an average of the output and inflation elasticities with respect to the CCyB vis-a-vis those elasticities with respect to the interest rate. The weights on the output and inflation elasticities depend on the policymaker's relative weight on output in the loss function, λ, and the slope of the Phillips Curve, κ. If $X > 0$, then the CCyB is a relatively more effective tool for achieving financial stability goals: it achieves a greater reduction in crisis probability than interest rates for a given macroeconomic cost. If $X = 0$, then neither tool has a comparative advantage and their setting is indeterminate. And if $X < 0$, the standard case is reversed and monetary policy becomes the instrument of choice for achieving financial stability goals.

4.2. Responses to different shocks

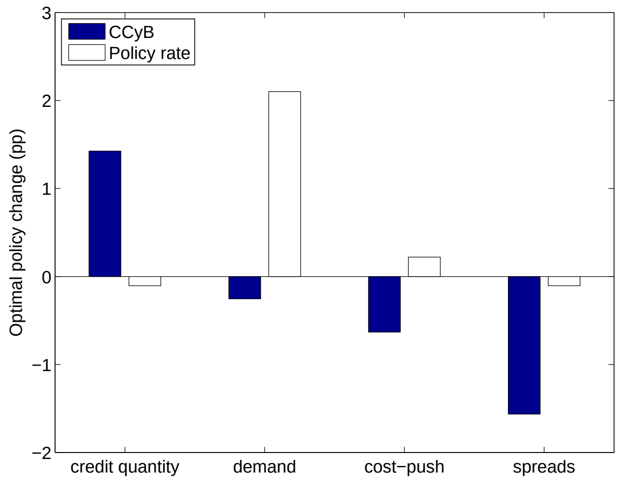
How should monetary policy and the CCyB be varied in response to the other shocks in the model, namely shocks to aggregate demand (ξ_1^y), cost-push shocks (ξ_1^π), and shocks to lending spreads (ξ_1^s)? To explore this question, Figure 5a presents optimal responses of the interest rate and CCyB to one standard deviation positive innovations to each of these shocks.

Starting with the case of a positive aggregate demand shock, the appropriate response is to tighten the interest rate significantly, leaving period 1 output little changed. There is little role for the CCyB in this case, although the calibration is loosened slightly because, with higher interest rates and hence lower credit growth, crisis risk falls, reducing the marginal benefit of maintaining the CCyB. By contrast, the optimal response to a positive cost-push shock is for the interest rate to tighten only a small amount, largely reflecting the need to achieve an appropriate balance between higher inflation and lower output. The CCyB is loosened slightly, which helps to offset the impact of the cost-push shock on inflation. In addition, with higher inflation, lower output and convex losses, the marginal cost of maintaining the CCyB increases.

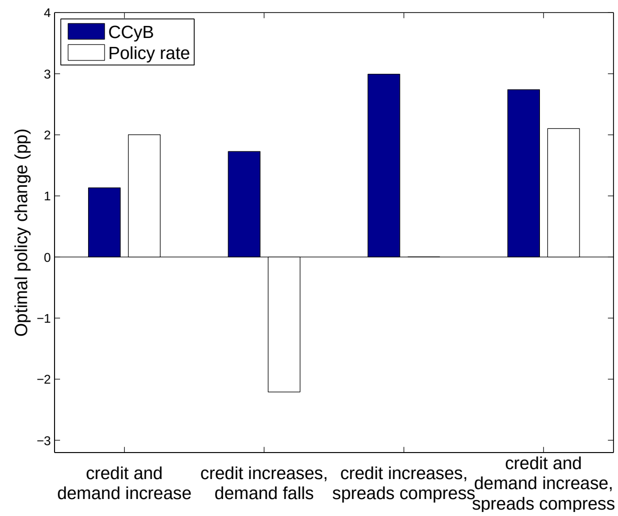
The final pair of columns in Figure 5a show the optimal response to the credit spread shock, which is the equivalent of a trade-off inducing shock for financial stability, since it results in tighter credit conditions in the near term without changing the fundamental risk of a crisis next period. It turns out to be optimal to loosen both instruments following this shock to cushion its impact on the economy, with the main response occuring via the CCyB. By acting in this way, the CCyB is balancing the need to offset the tightening in current credit conditions with the need to maintain a general level of resilience against the possibility of a crisis occuring next period. This policy prescription contrasts with the finding in Cúrdia and Woodford (2016). Their policymaker, with access only to a monetary policy tool, optimally cuts interest rates enough to offset much of the

Figure 5: *Optimal policy responses to shocks*

(a) *One standard deviation positive innovations*



(b) *Combinations of shocks*



Notes. This figure presents optimal responses of the CCyB (dark blue bars) and nominal interest rate (white bars) following various shocks. The left panel presents policy responses to one standard deviation innovations in credit (ξ_1^B) aggregate demand (ξ_1^y), cost-push shocks (ξ_1^π), and shocks to lending spreads (ξ_1^s). The right panel presents responses to *combinations* of shocks: in the first column, ξ_1^B and ξ_1^y both increase by one sd; in the second, ξ_1^B increases and ξ_1^y falls; in the third, ξ_1^B increases and ξ_1^s falls; and in the fourth, ξ_1^B and ξ_1^y both increase and ξ_1^s falls.

impact of the change in spread on borrowing rates. Similarly, in our model, a policymaker with access only to monetary policy (or the CCyB) would loosen by around twice (or 1.4 times) as much. With both tools available, the optimal mix involves loosening both instruments, but each by a lesser amount.

In practice, it is unlikely that these shocks would occur in isolation. Following an exogenous change in consumers' future income expectations, for instance, it is likely that both credit growth and aggregate demand would increase rapidly. We can attempt to capture such propogation mechanisms in our model by varying the correlation of the shocks. Figure 5b shows examples of the optimal response to one standard deviation shocks under the assumption that some are perfectly correlated with each other. The first pair of columns shows the case of perfectly positively correlated credit and demand shocks. This could also be thought of as the typical policy setting required when financial and business cycles are closely aligned.[15] With aggregate demand and credit growth both

[15] An alternative interpretation of this shock is that it captures the case where the quantity of credit enters the IS curve and thus influences the level of aggregate demand directly:

$$y_1 = E_1^{ps} y_2 - \sigma(i_1 - E_1^{ps} \pi_2 + \omega s_1) + q(B_1 - \phi_0) + \xi_1^y \tag{16}$$

increasing, both instruments should be tightened. The need to tighten monetary policy in response to the positive aggregate demand shock dominates the need to cushion the macroeconomic effects of the CCyB being tightened simultaneously. Similarly, the need to tighten the CCyB in response to the positive credit shock dominates the need to loosen in response to the rise in interest rates.

The second pair of columns column shows the optimal response to the same two shocks under the assumption that they are negatively correlated. This case could be thought of as capturing situations where financial stability risks increase, but inflationary pressures and growth are subdued.[16] In this case, the instruments optimally move in opposite directions: the CCyB tightens to offset the credit shock and the interest rate falls to offset the demand shock. Furthermore, their is instrument substitutability, which leads to additional policy changes in the same direction.

The final two pairs of columns present cases that could be considered to represent credit supply shocks, which involve both the quantity of credit increasing and spreads compressing. They also capture the main features of a model where the credit spread depends negatively on credit, or negatively on the policy rate, as in some formulations of the risk-taking channel of monetary policy.[17] The final pair of columns also includes a positive demand shock, capturing the case where credit and demand are more strongly positively correlated. In both cases, the optimal response is to tighten the CCyB by a large amount; this simultaneously increases the resilience of the banking system to the higher crisis probabililty and leans against the fall in loan spreads. It is optimal to leave the interest rate more or less unchanged unless aggregate demand also increases, in which case monetary policy optimally tightens as well. This final case captures what one might think of as a typical credit boom that also boosts output.

We end this section by looking at the historical correlation between credit growth and inflationary pressure in the United Kingdom – this is informative about the likelihood in future of interest rates and the CCyB needing to be adjusted in opposite directions. Figure 6 plots annual realisations of a

Substituting into this the equation for credit growth, (5), gives:

$$y_1 = E_1^{ps} y_2 - \overline{\sigma}(i_1 - E_1^{ps}\pi_2 + \overline{\omega} s_1) + \xi_1^y + q\xi_1^B \tag{17}$$

where $\overline{\sigma} = \sigma - q\phi_i$ and $\overline{\omega} = \omega - \frac{q\phi_s}{\sigma}$.

[16] As we discuss in the next section, it could also capture the case discussed in Svensson (2016) where a negative output gap in period 1 leads to a more costly crisis in period 2, because the crisis involves a fixed fall in output. Svensson's model actually uses unemployment as the measure of real activity, but rises in unemployment or the unemployment gap in his model could be interepreted as falls in output in ours.

[17] We are grateful for Andrea Ajello for suggesting the case where spreads depend negatively on the quantity of credit. The interaction of credit quantity and spread shocks captures the essence of his suggestion.

simple metric of business cycle that should guide the stance of monetary policy – the weighted sum of inflation and output gaps – with realisations of a summary statistic of the financial cycle that one might expect to be correlated with the authorities' stance on the CCyB – 3-year cumulative growth in the credit-to-GDP ratio.

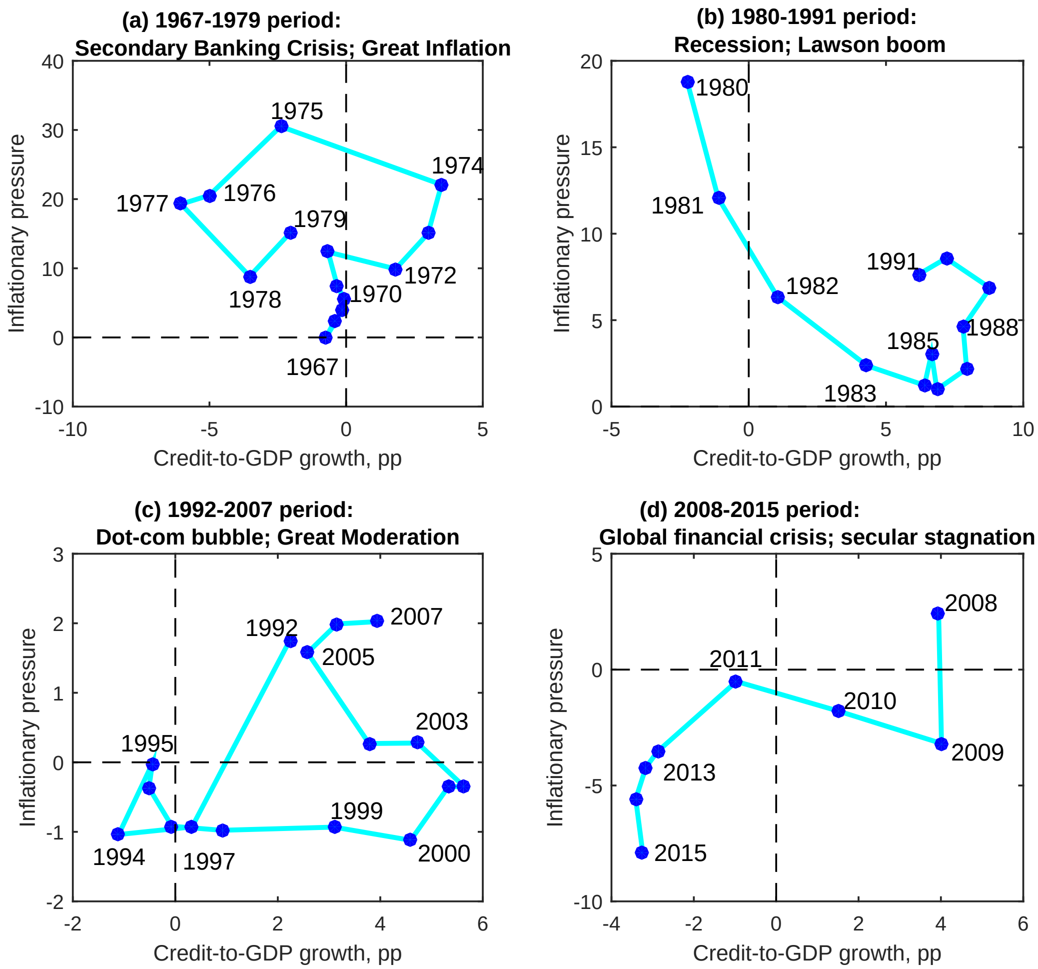
The correlation between these policy stance indicators is evidently highly unstable. The 1970s, for instance, witnessed the combination of a persistent build-up in inflationary pressure with weak credit growth; by contrast, the 1980s saw the reverse situation, with persistent declines in inflationary pressure coinciding with rapid credit growth. The correlation between credit growth and inflation pressure was close to zero for much of the 1990s and 2000s, with business and financial cycles seemingly disconnected. Yet in the decade that has followed the global financial crisis, these measures have been strongly positively correlated, with private sector deleveraging coinciding with declining inflationary pressure.

These data, combined with the model analysis presented above, emphasise that it is certainly possible – indeed, quite likely – that the CCyB and the nominal interest rate will need to be adjusted in opposite directions. Rather than signalling a policy conflict of any kind, this instead should be regarded as a natural product and strength of the overall policy regime. Indeed, the benefits of having an additional policy lever are most apparent in precisely these situations, where risks to financial stability are evolving in a way that is not closely linked to inflationary pressures, and hence the traditional aims of monetary policy.

5. Extensions to our benchmark model

In this final section, we consider a number of extensions to the basic model. First, we compare outcomes under the benchmark description of policy, whereby a single policymaker sets interest rates and the CCyB jointly to minimise an overall loss function comprising monetary and financial stability objectives, to that achieved when these tools are set in an uncoordinated manner by separate monetary and macroprudential authorities. Second, we consider how the results change when monetary policy is constrained by an effective lower bound. Third, we analyse the implications of the fact that monetary policy influences the actions of *all* financial market participants by changing the risk-free rate, whereas the CCyB applies to banks only and therefore suffer from a well-known

Figure 6: *Business–financial cycle correlations, United Kingdom: 1967-2015*



Notes. The figure presents historical correlations between indicators of business and financial cycles for the United Kingdom, across four sub-periods. The business cycle indicator shown on the y axis ('Inflationary pressure') is defined as $1.5(\pi_t - \pi_t^*) + 0.5(y_t - y_t^*)$, where π_t is the annual growth rate of the Consumer Price Index, π_t^* is the inflation target, assumed to be 2%, y_t is the level of real U.K. GDP, and y_t^* is an estimate of potential GDP given by a linear time trend. The financial cycle indicator shown on the x axis is defined as the 3-year cumulative growth rate of the credit-to-GDP ratio for the United Kingdom.

boundary problem (Stein, 2013).[18] Fourth, we consider the implications of the thesis that low interest rates encourage excessive risk-taking by certain financial market participants, particularly those with explicit or implicit nominal return targets (Rajan, 2006). And fifth, we consider arguments put forward for endogenising the *severity* of a financial crisis – in addition to its probability of occuring. Headline results from simulating the model under these various extensions are reported in Table 6,

[18]For instance, under the relevant EU legislation, the CCyB applies to all banks, building societies and large investment firms operating in the European Union. In the United States, it applies only to so-called 'Advanced Approach' banks.

and are discussed below.

Table 6: *Macroeconomic outcomes under different policy regimes and model variants*

Case	SD(y_1)	SD(π_1)	SD(B_1)	median(γ_1)	SD(i_1)	SD(k_1)	$E(L)$
Simulation using credit shocks only							
$\zeta = 0$:							
(i) Benchmark results under CCyB regime	0.11	0.005	5.3	0.77	0.11	1.45	1.37
(ii) Nash policies	0.10	0.005	5.3	0.94	0.10	1.33	1.41
(iii) ELB	0.09	0.030	5.5	1.73	0	0.76	2.61
(iv) Market-based finance	0.09	0.004	5.6	1.46	0.08	1.13	2.32
(v) Risk-taking channel	0.11	0.003	5.8	0.87	0.10	1.45	1.51
(vi) Endogenous crisis severity	0.13	0.007	5.2	2.37	0.13	1.74	1.34
$\zeta = 2$:							
(vii) Benchmark results under CCyB regime	0.13	0.006	5.2	0.40	0.13	1.74	2.48
(viii) Nash policies	0.13	0.006	5.2	0.51	0.12	1.65	2.55
(ix) ELB	0.14	0.046	5.4	1.19	0	1.15	5.79
(x) Market-based finance	0.09	0.003	5.6	1.24	0.08	1.18	6.02
(xi) Risk-taking channel	0.15	0.003	6.1	0.51	0.12	1.82	2.94
(xii) Endogenous crisis severity	0.12	0.006	5.2	2.07	0.12	1.57	1.91
Simulation using all shocks							
$\zeta = 0$:							
(xiii) Benchmark results under CCyB regime	0.17	0.008	5.4	0.74	2.05	2.2	1.53
(xiv) Nash policies	0.15	0.008	5.4	0.92	2.05	2.32	1.57
(xv) ELB	0.73	0.778	5.7	1.32	1.01	2.29	112.14
(xvi) Market-based finance	0.15	0.007	5.7	1.56	2.04	2.00	2.51
(xvii) Risk-taking channel	0.17	0.011	7.5	0.83	1.99	2.30	2.39
(xviii) Endogenous crisis severity	0.19	0.009	5.3	2.59	2.05	2.23	1.51
$\zeta = 2$:							
(xix) Benchmark results under CCyB regime	0.20	0.010	5.3	0.40	2.05	2.23	2.66
(xx) Nash policies	0.19	0.009	5.3	0.50	2.05	2.22	2.73
(xxi) ELB	0.69	0.777	5.6	0.87	0.96	2.95	116.04
(xxii) Market-based finance	0.17	0.007	5.7	1.31	2.04	1.83	6.30
(xxiii) Risk-taking channel	0.23	0.034	8.5	0.48	1.97	2.64	5.55
(xxiv) Endogenous crisis severity	0.21	0.011	5.3	2.30	2.05	1.89	2.11

Notes. The table presents results obtained by running a stochastic simulation of the model. The standard deviations of output (y_1), inflation (π_1), credit growth (B_1), the interest rate (i_1) and the CCyB (k_1) are reported in terms of annual percentage points; the median crisis probability (γ_1) is reported as an annual percentage rate; expected losses are reported as a per cent of losses incurred in the event of a financial crisis occuring in period 2. Results are reported for two alternative values of ζ, the relative weight placed on stabilising the crisis probability in the loss function. For both sets of results, expected losses are shown as a per cent of losses incurred in the event of a crisis assuming that $\zeta = 0$, $L_{2,c}|\zeta = 0$. For the market-based model, the share of market-based finance in total lending is calibrated as 25% ($b = 0.75$). In these rows B_1 refers to overall credit growth, given by the weighted average of that provided by banks and by markets. For the risk-taking channel model, the interaction coefficient is calibrated as $\phi_{is} = -1000$.

5.1. How large are the gains from policy coordination?

Up to this point, we have considered the case of a single policymaker who sets the interest rate and the CCyB jointly to minimise an overall loss function comprising both monetary policy and financial stability objectives. How large are the gains from these policies being set in a coordinated fashion in our benchmark model? What welfare losses would arise from an institutional arrangement in which these policy instruments are set by separate policymakers maximising distinct objectives?

To address these questions, we assign the monetary authority a loss function that aims to stabilise quadratic deviations of period 1 inflation and output from target – recall that a period in the model is assumed to last three years, so shocks that generate fluctuations in inflation and/or output beyond this horizon are assumed to not enter the monetary authority's calculus:

$$L_M = \frac{1}{2}(\pi_1^2 + \lambda y_1^2) \tag{18}$$

For the macroprudential authority, we assign a loss function that aims to minimise the crisis probability and which, in addition, penalises volatility in output – recognising that authorities with financial stability mandates typically seek to achieve an appropriate balance between enhancing financial stability and near-term economic growth.[19] This gives the following macroprudential policy loss function:[20]

$$L_F = \frac{1}{2}\lambda y_1^2 + \beta\gamma_1(1+\zeta)E_1[L_{2,c}] + \beta(1-\gamma_1)E_1[L_{2,nc}] \tag{19}$$

The first-order condition for the monetary authority is:

$$\sigma(\kappa\pi_1 + \lambda y_1) = 0 \tag{20}$$

Compared to the jointly optimal case given by equation (13), for a given setting of the CCyB, monetary policy under Nash policies is set looser than is optimal. This is because the monetary authority fails to take into account that raising interest rates creates a positive externality for financial

[19] The objective of the Bank of England's Financial Policy Committee is 'to protect and enhance the resilience of the UK's financial system and, subject to this, to support the Government's economic objectives including those for growth and employment'.

[20] Each loss function is minimised subject to the same set of constraints as the jointly optimal policy discussed in Section 2.2, also taking the other policymaker's reaction function as given.

stability via its effect in dampening credit growth, which reduces the probability of a crisis in the subsequent period.

The first-order condition for the macroprudential authority is:

$$\lambda y_1(-\sigma\omega\psi) = \frac{\partial\gamma_1}{\partial k_1}(-\frac{\partial L_F}{\partial\gamma_1}) \tag{21}$$

Relative to the jointly optimal case given by equation (14), for a given setting of monetary policy, the CCyB is set at a suboptimally low level under our benchmark calibration. The marginal cost of using macroprudential policy (given by the term on the left hand side of 21) depends on its effect on aggregate demand, rather than potential supply in equation (14). The Nash macroprudential authority is also missing the term that weights the marginal effect of changing the interest rate on the crisis probability. The differences arise because the macroprudential authority ignores the two externalities that the CCyB exerts on inflation: one via the output gap; and one via the cost-push effect of higher spreads on potential supply. If, as under our benchmark calibration, the CCyB has a larger impact on demand than supply, this will be a positive externality for the monetary policymaker. The Nash macroprudential authority fails to take account of this and consequently overstates the marginal cost of using the CCyB.[21]

How large are these distortions? Rows (ii), (viii), (xiv) and (xx) of Table 6 report summary statistics for the model's performance under the uncoordinated Nash regime. Overall, delegation has only a small effect on performance, as can be seen via a comparison with the benchmark results from Section 3, which are repeated in rows (i), (vii), (xiii) and (xix) for convenience. The standard deviations of inflation, output and credit growth are all virtually unchanged; the crisis probability increases somewhat, from 0.75 per cent to 0.92 per cent ($\zeta = 0$) and from 0.4 per cent to 0.5 per cent ($\zeta = 2$) in the full simulation, resulting in a minor increase in expected losses. Therefore, under our benchmark calibration, assigning monetary and macroprudential objectives to distinct policymakers achieves outcomes that are a close approximation to jointly-optimal policy. If there are material gains from splitting the assignment of macroprudential and monetary policy powers that are not captured in our simple framework, such as improved accountability or greater specialised expertise

[21]In the Nash equilibrium, the CCyB is also set suboptimally low under our benchmark calibration. While monetary policy is set suboptimally loose *conditional on the level of the CCyB*, it is nonetheless set tighter than the jointly optimal case, since the monetary authority's best response to a lower CCyB is to tighten monetary policy.

on committees, it seems likely that these could outweigh any losses resulting from less-than-fully coordinated policies.[22]

5.2. The effective lower bound on interest rates

How does recognition of the effective lower bound (ELB) on nominal interest rates affect the trade-offs faced by the policymaker? We examine this question in Figure 7a. The blue solid lines repeat the trade-off frontiers presented earlier when both instruments can be adjusted without limit; the red dashed lines show the equivalent frontiers when interest rates cannot fall below zero. With monetary policy unable to cushion its impact, using the CCyB becomes far more costly. As a result, the trade off facing the policymaker steepens, rotating out from the point on the horizontal axis where the CCyB is set at 0 per cent. Under our baseline calibration, the trade-off remains less steep than when monetary policy is the only instrument available. This reflects the comparative advantage of the CCyB in dealing with credit shocks that affect the crisis probability: the demand cost of a given reduction in the crisis probability is much smaller using the CCyB than with monetary policy.

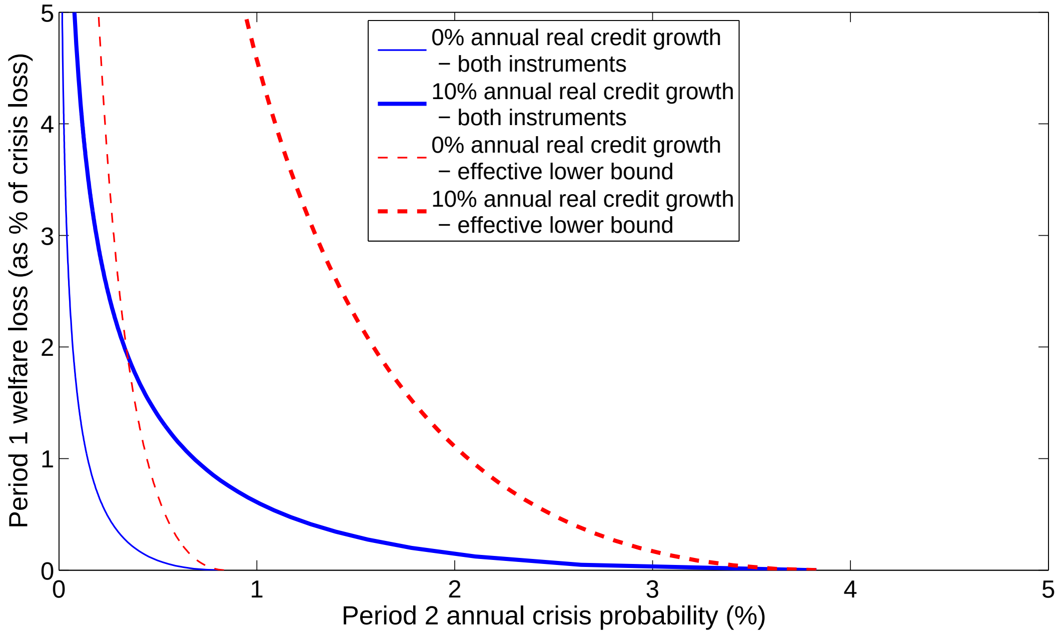
Given the steeper trade-off, it is optimal to vary the CCyB far less aggressively in the face of a credit shock when monetary policy is constrained by the ELB, as illustrated in Figure 7b. The CCyB required to mitigate the effects of 12.5 per cent credit growth on the crisis probability falls from around 5 per cent with unconstrained monetary policy to 1.5 per cent if monetary policy is constrained. This result in corroborated in the simulation of the model under credit shocks only reported in Table 6, upper panel, row (iii). At the ELB, we observe a large increase in the standard deviation of inflation and in the median crisis probability; and the standard deviation of the CCyB falls by one half. Expected losses increase substantially as a result.

To what extent does this finding of less aggressive CCyB usage when monetary policy is constrained at the ELB carry through to the full simulation of the model, with the complete set of shocks? The lower panel in Table 6 examines this case. A comparison of rows (xv) and (xiii), and (xxi) and (xix) shows that the standard deviations of output, inflation, and credit growth all increase significantly, as does the median annual crisis probability. Perhaps surprisingly, the volatility of the

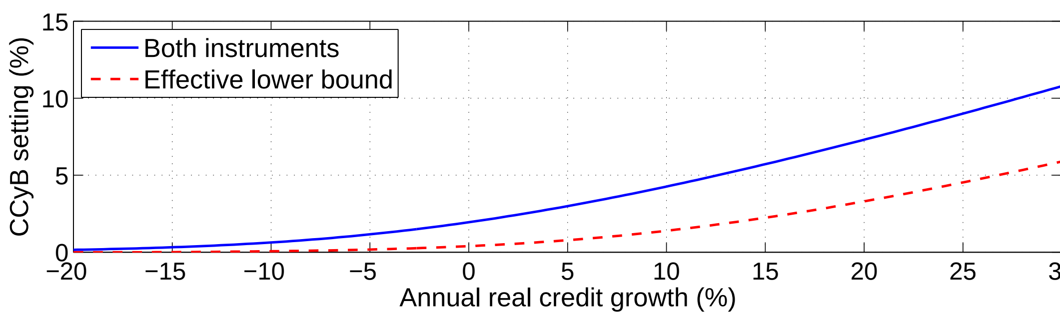
[22]We have also analysed the case where the macroprudential authority acts as a Stackelberg leader, setting the CCyB first, with the monetary authority then setting interest rates given the chosen CCyB. This delivers similar results to the Nash equilibrium case. Details are available from the authors.

Figure 7: *Monetary and financial stability trade-off at the effective lower bound for nominal interest rates*

(a) *The intertemporal trade-off*



(b) *CCyB policy function as credit shock varies, with and without binding effective lower bound*



Notes. For an explanation of the upper panel, see the note to Figure 3. The red dashed lines present the trade-off when monetary policy is constrained at the effective lower bound. For details of the lower panel, see the note to Figure 4b. The red dashed line shows the optimal setting of the CCyB as a function of annual real credit growth when monetary policy is constrained at the effective lower bound.

CCyB *increases* in this case. This is because, with monetary policy constrained, the CCyB is used as the primary macroeconomic stabilisation tool. Expected losses in the full simulation are extremely large – bigger than the cost of a crisis itself. This largely results from realisations of negative shocks that are large enough that both instruments are floored at their lower bounds. In those realisations, because our model does not allow for any substitute monetary or macroprudential instruments, output and inflation losses are huge.

In reality, unconventional monetary policies and other macroprudential tools could potentially be used at the ELB. These are outside the scope of our model, but the results suggest caution in using an instrument when the other is constrained. Ideally, such a situation would not arise. If a financial crisis increases the probability of reaching the ELB, resulting in higher losses, policymakers may want to place more weight on avoiding this outcome. We can model this by increasing ζ in our loss function, which results in a higher countercyclical capital buffer for a given level of credit growth.

5.3. 'Getting in all the cracks': Introducing a market-based financial sector

In this subsection, we extend the model to introduce a market-based finance sector that is not subject to the CCyB. This can be thought of as comprising insurance firms, investment funds, hedge funds and other non-bank entities. This allows us to analyse leakages from the application of the CCyB, in which the banking system is disintermediated by non-bank institutions who are able to hold debt liabilities of the private non-financial sector more cheaply than banks as a result of not needing to maintain a capital buffer. This introduces a limit to the effectiveness of the CCyB in reducing the crisis probability as it cannot lower the probability of a crisis emanating from the market-based financial system.

Let the probability of a crisis in the extended model be given by:

$$\gamma_1 = b\gamma_1^B + (1-b)\gamma_1^M \tag{22}$$

where $\gamma_1^i = \frac{exp(h_0^i + h_B B_1^i + h_k^i k_1)}{1+exp(h_0^i + h_B B_1^i + h_k^i k_1}$, $i = B, M$, is the probability of a crisis arising in the banking sector and market-based finance sector respectively. And the parameter b is the share of credit held by banks in steady state. As a rough metric of the empirical counterpart of b, as of 2015, non-banks accounted for slightly under 50% of total UK financial system assets (Bank of England, 2016*a*).

Lending growth in each sector is determined by a process analogous to equation (5):

$$B_1^B = \phi_0^B + \phi_i i_1 + \phi_s^B s_1 + \xi_1^B \tag{23}$$

$$B_1^M = \phi_0^M + \phi_i i_1 + \phi_s^M s_1 + \xi_1^M \quad (24)$$

We assume $\phi_s^B < 0$ and $\phi_s^M > 0$; that is, following an increase in the CCyB that pushes up bank lending spreads, there is an increase in the share of credit liabilities held by market-based financial institutions. The interest elasticity of credit demand is the same in both sectors, however, capturing the Stein (2013) argument that monetary policy 'gets in all the cracks'. In addition, we assume that $h_k^M = 0$, reflecting the fact that an increase in the CCyB does not enhance resilience in the market-based finance sector. For simplicity, we assume that both shocks are perfectly correlated, $\xi_1^B = \xi_1^M$, and we calibrate h_0^M so that the market-based finance sector has the same steady state crisis probability as the banking sector. Note that this assumes an unregulated market-based finance sector but a banking sector with a steady-state capital ratio of 11%, i.e. the market-based sector is assumed to be somewhat less systemically risky than the banking sector. For simplicity, we assume that h_B is the same in each sector.

We calibrate the 'leakage' effect such that, for every percentage point reduction in bank credit growth caused by an increase in the CCyB, the market-based finance sector increases its lending growth by 0.33 percentage points; that is, we set $b\phi_s^M = -0.33(1-b)\phi_s^B$.[23] This is based on the Aiyar, Calomiris and Wieladek (2014) study of the leakage to UK-resident foreign branches when supervisory capital requirements are increased for domestically incorporated banks. The authors find this leakage to be substantial: about one third of the reduction in lending by domestic banks following an increase in required capital is offset by an increase in lending by foreign branches.[24]

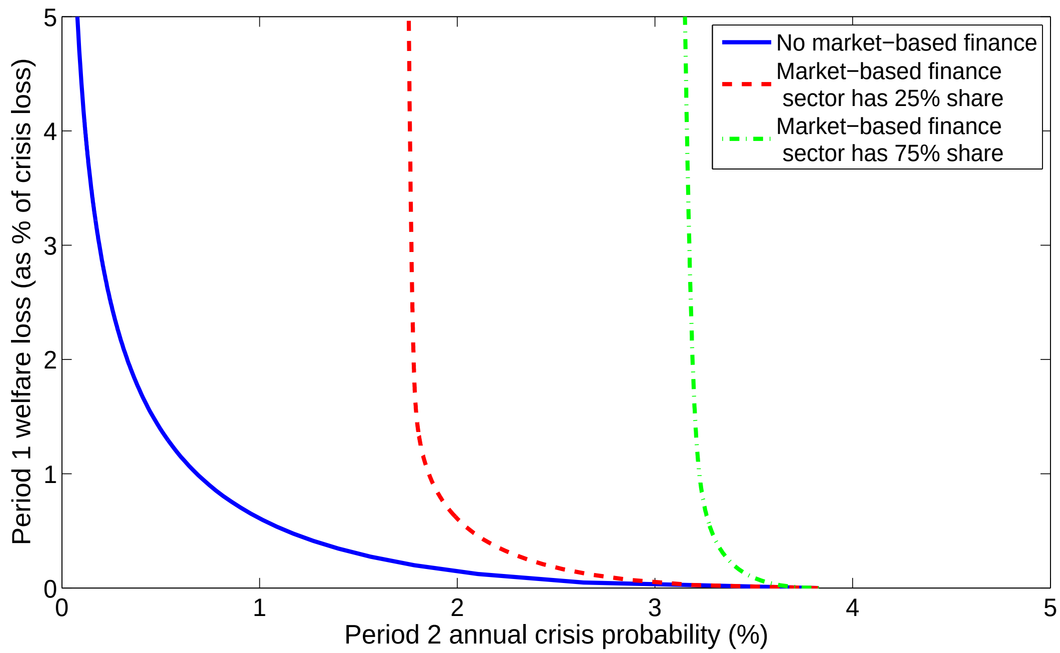
Figure 8a shows how the introduction of a market-based finance sector affects the key intertemporal trade-off between monetary and financial stability examined in this paper. The red dashed line shows the trade-off for a market-based finance sector that accounts for 25% of lending; the green dash-dotted line shows the equivalent trade-off when this sector accounts for 75% of lending. In both cases the trade-off worsens relative to the benchmark model (shown by the blue solid line)

[23] We keep the size of the leakage constant at 0.33 as we vary b, implying that the parameter ϕ_s^M is different depending on the share of market-based finance in total lending.

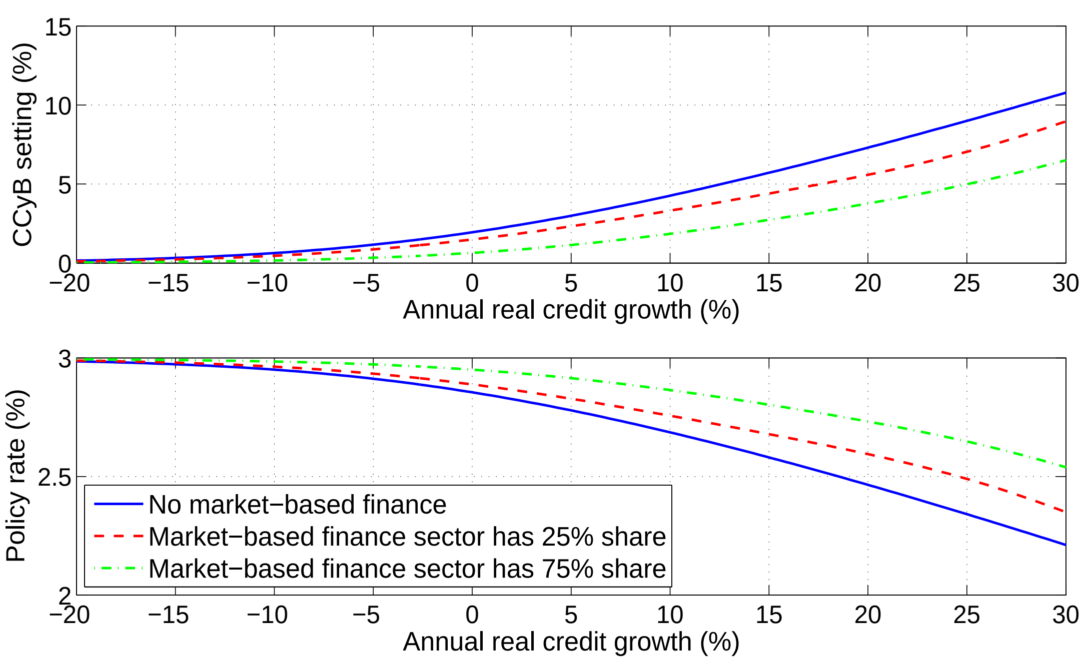
[24] Cizel et al. (2016) find evidence of substitution effects from bank towards nonbank credit, especially in advanced economies, when macroprudential policies are applied to the banking sector. However, they use indicator variables for all kinds of macroprudential measures rather than specific changes in capital requirements which means that we cannot use their results directly for calibration.

Figure 8: *Monetary and finance stability policy with a market-based finance setor of varying magnitudes*

(a) *The intertemporal trade-off*



(b) *Policy functions for the nominal interest rate and CCyB*



Notes. For details of the upper panel, see the note to Figure 3. The blue solid line shows the intertemporal trade-off facing an economy with no market-based finance sector and real credit growth of 10% per year. The red dashed and green dash-dotted lines show the trade-off in an economy where market-based finance sector has a 25% and 75% share in total credit. For details of the lower panel, see the note to Figure 4b.

because any positive setting of the CCyB generates smaller financial stability benefits. It is striking that, at crisis probabilities of just under 2% per year for the 25% market-based finance sector case and at just over 3% per year for the 75% case, the frontier becomes almost vertical. At these points, the financial stability benefits of tightening the CCyB become very small, as further reductions in the banking sector crisis probability are largely offset by leakages that increase the crisis probability of the market-based finance sector.

Figure 8b illustrates how optimal policy responses as a function of credit growth change in this case. The larger the market-based finance sector, the less active policy should be: in the face of a credit boom, the CCyB should tighten less and as a consequence interest rates should be cut by less. Of course, our model abstracts from other macroprudential policies that could also affect the market-based finance sector, e.g. borrower-based tools such as restrictions on loan-to-value or loan-to-income ratios on household borrowing; or requirements applied directly to market-based finance institutions. If leakages are significant, our results highlight the need to consider deploying such tools alongside bank-based macroprudential policies. Moreover, Gambacorta, Yang and Tsatsaronis (2014) find evidence that financial crises have lower output costs in countries with a higher share of market-based finance. In that case, policymakers may still opt to use the CCyB aggressively in the presence of market-based finance, since expected losses from that sector would be overstated by looking at the crisis probability alone.

Table 6 presents the impact of the market-based finance extension on key model summary statistics. Relative to the benchmark case, the volatility of total credit growth increases, while the volatilites of output and inflation fall. The median crisis probability also increases significantly. These differences are because the CCyB becomes less effective in the presence of a market-based sector. It is therefore optimal to use it less: the volatility of the CCyB falls from 2.28 percentage points to 2.00 percentage points in the full simulation with ζ equal to 0.

5.4. Introducing a 'risk-taking channel' of monetary policy

We next extend the benchmark model to capture the idea that, when policy rates are low and capital requirements are high, banks are incentivised to take on excessive risk in order to meet return on equity targets. We do so by augmenting equation (5) to introduce a non-linear interaction term between the interest rate and the CCyB.[25] This is consistent with Dell'Ariccia, Laeven and Suarez (2017), who find that the risk-taking propensity of U.S. banks is negatively correlated with real policy rates, but that the correlation is less pronounced when banking system capital is weak.

In this extension, B_1 is determined by:

$$B_1 = \phi_0 + \phi_i i_1 + \phi_s s_1 + \phi_{i,s} i_1 s_1 + \xi_1^B, \tag{25}$$

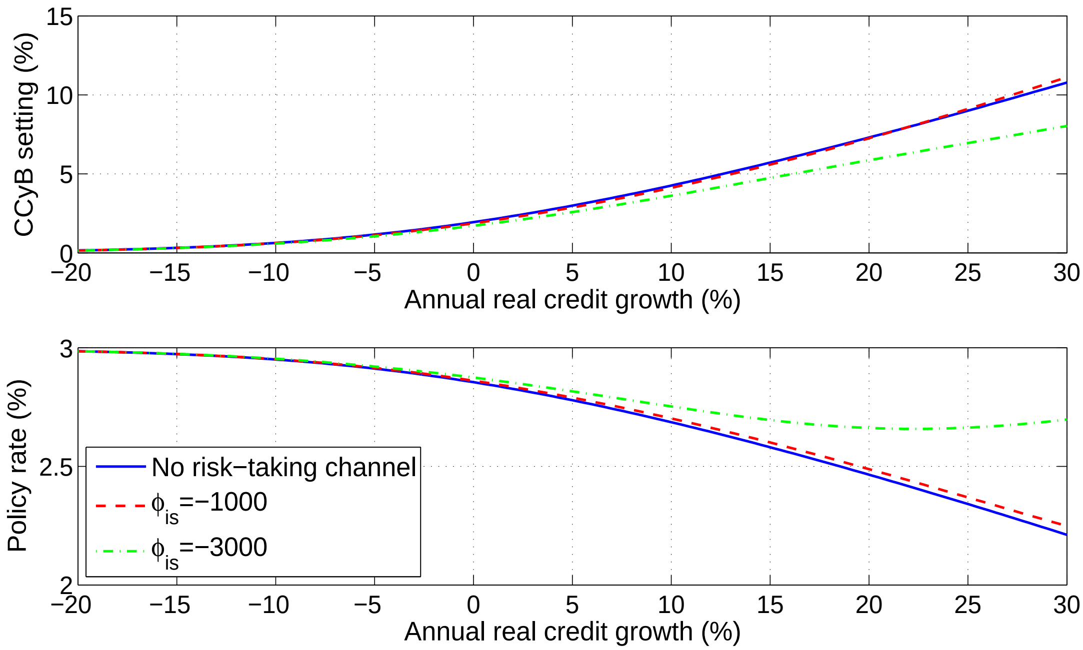
where $\phi_{i,s} < 0$ and B_1 should be re-interpreted as capturing the riskiness of the credit extended by the banking sector, which may increase even if the quantity of credit remains unchanged. Under this formulation, the CCyB becomes less effective at constraining risk-adjusted credit growth when interest rates are low.

The consequences for optimal policy are illustrated in Figure 9. The red dashed lines set an interaction coefficient of $\phi_{i,s} = -1000$, which implies that with interest just 60 basis points below their steady state level, the marginal impact of tightening the CCyB switches from reducing risk-adjusted credit growth to increasing it. In this case, the results are still little changed, because this cost is outweighed by the resilience benefits of using the CCyB. If the interaction coefficient is set to a extremely high level, $\phi_{i,s} = -3000$ (green dash-dotted lines), the optimal policy changes more markedly. As the credit boom expands, the benchmark-model response of tightening the CCyB and reducing interest rates now becomes much less effective. Indeed, at very elevated levels of credit growth, we observe a qualitative change in the optimal response of monetary policy, which switches from loosening further to tightening, albeit slightly. However, this result only holds if the risk-taking channel of monetary policy is so strong as to offset the resilience benefits of the CCyB even when interest rates are only marginally below their steady state level.

The impact on overall macroeconomic performance is summarised for the moderate parameter ($\phi_{i,s} = -1000$) in Table 6. Relative to the benchmark case, we observe significantly greater volatilities in credit and when $\zeta = 2$, also for inflation. The standard deviation of the interest rate falls, however, reflecting the additional stability costs associated with an expansionary policy stance.

[25] An alternative way of introducing a risk-taking channel of monetary policy to the model would be to allow credit spreads to be correlated with the level of interest rates. Given the endogenous cost-push effect of credit spreads in our Phillips Curve, this would be equivalent to introducing a cost channel of monetary policy (Ravenna and Walsh, 2006). This would make using macroprudential policy less costly, since monetary policy would be able to offset some of its cost-push effects as well as its effects on demand. But unlike the approach taken here, it would not qualitatively change the results presented in Section 3.

Figure 9: *Optimal policy responses to a credit boom: benchmark model vs risk-taking channel extension*



Notes. The chart presents optimal responses of the interest rate and CCyB for varying levels of annual real credit growth. The solid blue lines show responses in the benchmark model analysed in Section 3. The red dashed lines and the green dash-dotted lines show responses with a risk-taking channel calibrated as $\phi_i, s = -1000$ and $\phi_i, s = -3000$.

5.5. Endogenising the severity of crises

Up to this point, we have modelled the financial stability effects of monetary and macroprudential policies as operating by reducing the *probability* of a crisis occurring. Here, we consider the implications of two alternative ways of endogenising the severity of crises. The first is due to Svensson (2016), who argues that crises are likely to result in a fixed increase in the unemployment rate - say, by 5 percentage points - making the level it reaches in the crisis state a function of its period 1 reading. The second is due to Jordà et al. (2017), who provide empirical evidence that higher bank capital accelerates recoveries from financial crisis recessions, but has no discernable impact on crisis probability.

5.5.1 The 'fixed impact' view of crises

A simple way of capturing the Svensson (2016) argument in our model is to treat period 2 output in the crisis state as a direct function of its period 1 level:

$$y_{2,c} = c_0 + c_y y_1 \tag{26}$$

That is, the higher the level of output in the first period, the lower the severity of the crisis state.

Intuitively, this strengthens the substitutability between the instruments: it becomes more important that monetary policy cushions any negative aggregate demand effects of deploying the CCyB.[26] In the limiting case where we shut off the transmission mechanism of the CCyB (i.e. set $\psi = h_k = 0$), we obtain Svensson's result: that for a sufficiently positive c_y, the marginal effect of tighter monetary policy is to increase the expected crisis loss, so the optimal strategy is to lean *with* the wind, i.e. to reduce interest rates during a credit boom. Efforts to lean against the wind *ex ante* will worsen the severity of crises by weakening the economy at the point the crisis hits.

5.5.2 Bank capital affects crisis severity, but not likelihood

In a recent paper, Jordà et al. (2017) analyse the empirical relationship between bank capital and financial crises, using long time series for a panel of advanced economies. They find that the capital ratio has no value as a crisis predictor, but that higher capital ratios significantly speed up an economy's recovery from a crisis-induced recession. Bridges, Jackson and McGregor (2017) report a similar finding. This could reflect better capitalised banks needing to delever their balance sheets by less when adverse shocks strike; it could also reflect the benefits of having strongly capitalised banks who can step in when weak banks fail (BCBS, 2010b).

To operationalise this view, we recalibrate the model by setting $h_k = 0$ and by making the crisis level of output a function of banks' capital:

$$y_{2,c} = c_0 + c_k k_1 \tag{27}$$

[26]The effect is similar to increasing the weight, λ, on period 1 output in the loss function. We would obtain similar results if the crisis severity remained exogenous, but period 2 non-crisis output depended on period 1 output via a hysteresis channel, as in Kapadia (2005).

The authors find that a 10% increase in the capital ratio at the onset of a crisis (relative to a country-specific mean) is correlated with cumulative GDP per capita in the event of a crisis being 3.3% higher by end of year 3. For an initial capital ratio of 11%, and assuming for simplificity that these benefits are spread out linearly each year, we therefore set $c_k = 1$. We also set $c_0 = 0.04$, which implies that the crisis cost is the same as in the exogenous crisis severity case studied earlier.

The implications of endogenising the crisis severity in this way are reported in Table 6. Overall, the results are similar to the benchmark case. While we have shut down the impact of the CCyB on the probability of a crisis, we have introduced a new channel that operates via its loss given default. As the policymaker cares about expected losses, the policy problem is similar, and with this calibration, optimal policy is relatively unchanged.

There are, however, two differences that merit discussion. First, the median crisis probability is significantly higher in the endogenous severity case. The policymaker chooses not to reduce this probability by hiking interest rates, given the macroeconomic costs of such an actions. Instead, they deploy the CCyB to reduce the severity of the crises that do occur. Second, the standard deviation of the CCyB falls as we increase ζ, the relative weight placed on financial stability considerations in the loss function. The reason for this perhaps counterintuitive result is that, with higher ζ, the policymaker increases the average level of the CCyB; the average CCyB rises, meaning higher capital overall but with a lower variance.

6. Conclusion

We present a simple framework that allows us to explore how monetary and macroprudential policies affect the economy and interact with each other. We find that deploying the CCyB improves outcomes significantly relative to when monetary policy is the only tool – this reinforces the rationale for having expanded central banks' toolkits to include this policy lever. But despite its powerful role, the CCyB should be used less aggressively when monetary policy is constrained at the effective lower bound. The benefits of coordinating these policy levers are typically small and similar economic performance can be achieved by distinct policymakers pursuing distinct objectives. The instruments are substitutes in our benchmark model: faced with a credit boom, it is optimal to tighten the CCyB and to cushion its macroeconomic impact by loosening monetary policy. However, if the market-based finance sector is large and the risk-taking channel of monetary policy is strong, they become complements, and monetary policy and the CCyB should be used in conjunction to lean against credit booms.

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A. Solving the model

A.1. Minimising the loss function

The period 1 policymaker chooses period 1 settings of the CCyB and interest rates to minimise the loss function:

$$L = \frac{1}{2}(\pi_1^2 + \lambda y_1^2) + \beta\gamma_1(1+\zeta)E_1[L_{2,c}] + \beta(1-\gamma_1)E_1[L_{2,nc}] \tag{28}$$

subject to the Phillips Curve:

$$\pi_1 = \kappa y_1 + E_1^{ps}\pi_2 + \nu s_1 + \xi_1^{\pi} \tag{29}$$

the IS curve:

$$y_1 = E_1^{ps}y_2 - \sigma(i_1 - E_1^{ps}\pi_2 + \omega s_1) + \xi_1^{y} \tag{30}$$

the equation determining credit growth:

$$B_1 = \phi_0 + \phi_i i_1 + \phi_s s_1 + \xi_1^{B} \tag{31}$$

the equation for credit spreads:

$$s_1 = \psi k_1 + \xi_1^{s} \tag{32}$$

and the crisis probability equation:

$$\gamma_1 = \frac{\exp(h_0 + h_B B_1 + h_k k_1)}{1 + \exp(h_0 + h_B B_1 + h_k k_1)} \tag{33}$$

So the policymaker's problem is

$$min_{i_1,k_1} L = \frac{1}{2}(\pi_1^2 + \lambda y_1^2) + \beta\gamma_1(1+\zeta)E_1[L_{2,c}] + \beta(1-\gamma_1)E_1[L_{2,nc}] \tag{34}$$

subject to (29)-(33).

We then substitute (29) in place of π_1 in (34), (30) in place of y_1 and (32) in place of s_1. Note that $E_1[L_{2,c}]$, $E_1[L_{2,nc}]$, $E_1^{ps}\pi_2$, and $E_1^{ps}y_2$ are exogenous parameters from the perspective of the period 1 policymaker.[27] Differentiating with respect to i_1 and k_1 gives the two first order necessary conditions which hold at the minimised value of L:[28]

$$\frac{\partial L}{\partial i_1} = -\sigma(\kappa\pi_1 + \lambda y_1) + \frac{\partial \gamma_1}{\partial i_1}\beta((1+\zeta)E_1[L_{2,c}] - E_1[L_{2,nc}]) = 0 \tag{35}$$

$$\frac{\partial L}{\partial k_1} = -\sigma\omega\psi(\kappa\pi_1 + \lambda y_1) + \nu\psi\pi_1 + \frac{\partial \gamma_1}{\partial k_1}\beta((1+\zeta)E_1[L_{2,c}] - E_1[L_{2,nc}]) = 0 \tag{36}$$

In the absence of financial stability considerations ($\zeta = -1$), the loss function is globally convex and these first order conditions are also sufficient to define a global minimum.[29] For $\zeta > -1$, a sufficient condition for (35) and (36) to define a global minimum is that:

Condition 1. *At the settings of i_1 and k_1 that would be optimal in the absence of financial stability considerations, the loss function is in the convex region where $\gamma_1 < 0.5$.*

To see why, first note that the terms in the loss function in π_1 and y_1 are always convex, while the term in γ_1 is convex in the region where $\gamma_1 < 0.5$ and concave otherwise. So the loss function is guaranteed to be convex as long as $\gamma_1 < 0.5$. Second, starting at the point where i_1 and k_1 are optimal in the absence of any financial stability concerns, then any increase in γ_1 would make losses strictly higher, since period 1 loss is already minimised, and a higher γ_1 would increase expected period 2 loss. It follows that for the range of candidate optimal instrument settings, the crisis probability must be no higher than it would be in the absence of financial stability considerations. If Condition 1 also holds, this further implies that for the entire range of candidate solutions, $\gamma_1 < 0.5$ and therefore the loss function is convex. So the first order condtions are also sufficient to define a global minimum.

If Condition 1 were not true, it would imply in our model that the business and credit cycles

[27]The private sector ignores the possibility of a financial crisis, and conditional on a crisis not occurring, the policymaker is constrained to act in a time-consistent manner in period 2, so cannot manipulate the private sector's expectations. At time $t = 1$, the values of the private sector's expectations are therefore known by the policymaker, and *independent of period 1 policy*. So the period 1 policymaker's problem reduces to a static problem.

[28]In the monetary policy only case, (35) is the sole first order condition.

[29]Also assuming that $E_1[L_{2,nc}] = 0$, as in our calibration. If $E_1[L_{2,nc}] > 0$, then there are financial stability concerns unless $\zeta = -1 + \frac{E_1[L_{2,nc}]}{E_1[L_{2,c}]}$.

had become so misaligned that with inflation at target and output equal to potential, the crisis probability was greater than 50 per cent per year. While theoretically possible, such an extreme misalignment seems unrealistic, particularly in light of our empirical model estimate that the UK crisis probability peaked at only around 12 per cent in the 2000s. We therefore opt to ignore the extreme regions of the parameter space, or shock realisations, where Condition 1 does not hold.[30]

To gain some intuition into the first order conditions, we can substitute into the crisis probability (33), the equation determining credit growth (31), as well as the Phillips Curve (29), IS curve (30) and the equation for spreads (32), to give an equation in terms of the two policy instruments. Differentiating this using the chain rule gives the two marginal crisis risk equations:

$$
\begin{aligned}
\left(\frac{\partial \gamma_1}{\partial i_1}\right)_{k_1} &= \left(\frac{\partial \gamma_1}{\partial B_1}\right)_{k_1,i_1}\left(\frac{\partial B_1}{\partial i_1}\right)_{k_1} \\
&= \left(\frac{\exp(h_0 + h_B B_1 + h_k k_1)}{(1+\exp(h_0 + h_B B_1 + h_k k_1))^2} h_B\right)\left(\frac{\partial B_1}{\partial i_1}\right)_{k_1} \\
&= \frac{\exp(h_0 + h_B B_1 + h_k k_1)}{(1+\exp(h_0 + h_B B_1 + h_k k_1))^2} h_B \phi_i
\end{aligned} \tag{37}
$$

$$
\begin{aligned}
\left(\frac{\partial \gamma_1}{\partial k_1}\right)_{i_1} &= \left(\frac{\partial \gamma_1}{\partial B_1}\right)_{k_1,i_1}\left(\frac{\partial B_1}{\partial k_1}\right)_{i_1} + \left(\frac{\partial \gamma_1}{\partial k_1}\right)_{B_1,i_1} \\
&= \left(\frac{\exp(h_0 + h_B B_1 + h_k k_1)}{(1+\exp(h_0 + h_B B_1 + h_k k_1))^2} h_B\right)\left(\frac{\partial B_1}{\partial k_1}\right)_{i_1} + \left(\frac{\exp(h_0 + h_B B_1 + h_k k_1)}{(1+\exp(h_0 + h_B B_1 + h_k k_1))^2} h_k\right) \\
&= \frac{\exp(h_0 + h_B B_1 + h_k k_1)}{(1+\exp(h_0 + h_B B_1 + h_k k_1))^2} (h_B(\psi\phi_s) + h_k)
\end{aligned} \tag{38}
$$

Which means the *relative effect* of each policy on the crisis risk is a constant parameter:

$$
\frac{\frac{\partial \gamma_1}{\partial k_1}}{\frac{\partial \gamma_1}{\partial i_1}} = \frac{h_B \psi \phi_s + h_k}{h_B \phi_i} \tag{39}
$$

[30]In practice, we do this by finding the optimal policy for each shock realisation when $\zeta = -1$, and checking that the crisis probability is less than 50% at this point.

Next, multiplying through (35) by $-\frac{\frac{\partial \gamma_1}{\partial k_1}}{\frac{\partial \gamma_1}{\partial i_1}}$, and adding to (36), gives:

$$(\frac{\frac{\partial \gamma_1}{\partial k_1}}{\frac{\partial \gamma_1}{\partial i_1}}\sigma - \sigma\omega\psi)(\kappa\pi_1 + \lambda y_1) + \nu\psi\pi_1 = 0 \tag{40}$$

This can be be expressed as

$$\overline{\lambda} y_1 + \kappa\pi_1 = 0 \tag{41}$$

where

$$\overline{\lambda} \equiv \frac{\chi\sigma\omega\psi}{\frac{\nu\psi}{\kappa} + \chi\sigma\omega\psi}\lambda \tag{42}$$

and χ is a parameter defined as the comparative advantage of macroprudential policy at affecting the crisis probability, versus monetary policy at affecting the IS curve/aggregate demand. And $\frac{\nu\psi}{\kappa}$ is the marginal effect of macroprudential policy on the natural rate of output.

$$\chi \equiv \frac{h_B\phi_s\psi + h_k}{h_B\phi_i\omega\psi} - 1 = \frac{\frac{\partial \gamma_1}{\partial k_1}}{\frac{\partial \gamma_1}{\partial i_1}}\frac{\frac{\partial y_1}{\partial i_1}}{\frac{\partial y_1}{\partial k_1}} - 1 \tag{43}$$

In addition (35) can be multiplied by $(\frac{\nu\psi}{\kappa\sigma} - \omega\psi)$ and added to (36) to give an intertemporal optimality condition trading off changes in the crisis probability with output/inflation losses in period 1:

$$\lambda y_1(-\frac{\nu\psi}{\kappa}) = (\frac{\partial \gamma_1}{\partial k_1} + \frac{\partial \gamma_1}{\partial i_1}(\frac{\nu\psi}{\kappa\sigma} - \omega\psi))(-\frac{\partial L}{\partial \gamma_1}) \tag{44}$$

where $\frac{\partial L}{\partial \gamma_1}$ is the policymaker's expected discounted cost of a financial crisis, taking into account the extra weight ζ that they place on the expected cost of a crisis.

$$\frac{\partial L}{\partial \gamma_1} = \beta((1+\zeta)E_1[L_{2,c}] - E_1[L_{2,nc}]) \tag{45}$$

At the optimal setting of policy, the marginal loss from changing output is equated to that from changing inflation. So the condition can equivalently be expressed as an optimality condition trading off inflation today with the cost of a financial crisis tomorrow (with output today unchanged.) This gives:

$$\pi_1 \frac{\partial \pi_1}{\partial k_1} = (\frac{\partial \gamma_1}{\partial k_1} - \frac{\partial \gamma_1}{\partial i_1} \frac{\frac{\partial y_1}{\partial k_1}}{\frac{\partial y_1}{\partial i_1}})(-\frac{\partial L}{\partial \gamma_1}) \tag{46}$$

The LHS is the marginal cost of increasing inflation through the cost-push effect of higher credit spreads. This is set equal to the marginal gain from a lower crisis probability, made up of two terms. The first term on the RHS is the marginal gain from a lower crisis probability of higher spreads. The second is the marginal increase in the crisis probability from offsetting the demand effects of higher spreads using interest rates.

A.2. Policy settings and instrument substitutability

Substituting (29) in place of π_1 in (41) and (32) in place of s_1 gives:

$$\kappa^2 y_1 + \kappa E_1^{ps} \pi_2 + \kappa \nu \psi k_1 + \kappa \nu \xi_1^s + \kappa \xi_1^\pi + \overline{\lambda} y_1 = 0 \tag{47}$$

This can be rearranged to give:

$$y_1 = -\frac{\kappa}{\kappa^2 + \overline{\lambda}} (E_1^{ps} \pi_2 + \nu \psi k_1 + \nu \xi_1^s + \xi_1^\pi) \tag{48}$$

Substituting into this (30) in place of y_1 and (32) in place of s_1, then rearranging, gives an equation for the optimal setting of i_1, as a function of the optimal setting of k_1, shocks and exogenous variables:

$$i_1 = \frac{\kappa}{\sigma(\kappa^2 + \overline{\lambda})} (E_1^{ps} \pi_2 + \nu \psi k_1 + \nu \xi_1^s + \xi_1^\pi) + \frac{E_1^{ps} y_2 + \xi_1^y}{\sigma} - \omega \psi k_1 - \omega \xi_1^s + E_1^{ps} \pi_2 \tag{49}$$

The instruments are instrument substitutes iff, at the optimal settings of each instrument, $\frac{di}{dk} < 0$. Differentiating (49) gives:

$$\frac{di_1}{dk_1} = \frac{\kappa}{\sigma(\kappa^2 + \overline{\lambda})} \nu \psi - \omega \psi \tag{50}$$

This is less than zero iff:

$$\frac{\kappa}{\kappa^2+\overline{\lambda}}\nu\psi < \sigma\omega\psi \tag{51}$$

Otherwise there is instrument complementarity.

To find which direction the instruments move in response to a credit shock, note that (49) is independent of ξ_1^B, so $\frac{di_1}{d\xi_1^B} = \frac{di_1}{dk_1}\frac{dk_1}{d\xi_1^B}$. We can also substitute in (48) in place of y_1 in (44), then rearrange and substitute out for $\overline{\lambda}$ using (42) to give:

$$\begin{aligned}
k_1 &= \frac{\kappa^2+\overline{\lambda}}{\lambda\nu^2\psi^2}\Big(\frac{\partial\gamma_1}{\partial k_1} + \frac{\partial\gamma_1}{\partial i_1}\Big(\frac{\nu\psi}{\kappa\sigma} - \omega\psi\Big)\Big)\Big(-\frac{\partial L}{\partial\gamma_1}\Big) - \frac{E_1^{ps}\pi_2}{\nu\psi} - \frac{\xi_1^\pi}{\nu\psi} - \frac{\xi_1^s}{\psi} \\
&= \frac{\kappa^2+\overline{\lambda}}{\lambda\sigma\nu^2\psi^2}\Big(\sigma\omega\psi\Big(\frac{\frac{\partial\gamma_1}{\partial k_1}}{\frac{\partial\gamma_1}{\partial i_1}\omega\psi} - 1\Big) + \frac{\nu\psi}{\kappa}\Big)\frac{\partial\gamma_1}{\partial i_1}\Big(-\frac{\partial L}{\partial\gamma_1}\Big) - \frac{E_1^{ps}\pi_2}{\nu\psi} - \frac{\xi_1^\pi}{\nu\psi} - \frac{\xi_1^s}{\psi} \\
&= \frac{\kappa^2+\overline{\lambda}}{\lambda\sigma\nu^2\psi^2}\Big(\chi\sigma\omega\psi + \frac{\nu\psi}{\kappa}\Big)\frac{\partial\gamma_1}{\partial i_1}\Big(-\frac{\partial L}{\partial\gamma_1}\Big) - \frac{E_1^{ps}\pi_2}{\nu\psi} - \frac{\xi_1^\pi}{\nu\psi} - \frac{\xi_1^s}{\psi} \\
&= \frac{\kappa^2+\overline{\lambda}}{\lambda\sigma\nu^2\psi^2}\chi\sigma\omega\psi\frac{\lambda}{\overline{\lambda}}\frac{\partial\gamma_1}{\partial i_1}\Big(-\frac{\partial L}{\partial\gamma_1}\Big) - \frac{E_1^{ps}\pi_2}{\nu\psi} - \frac{\xi_1^\pi}{\nu\psi} - \frac{\xi_1^s}{\psi} \\
&= \frac{(\kappa^2+\lambda)\chi\sigma\omega\psi + \kappa^2\frac{\nu\psi}{\kappa}}{\lambda\sigma\nu^2\psi^2}\frac{\partial\gamma_1}{\partial i_1}\Big(-\frac{\partial L}{\partial\gamma_1}\Big) - \frac{E_1^{ps}\pi_2}{\nu\psi} - \frac{\xi_1^\pi}{\nu\psi} - \frac{\xi_1^s}{\psi}
\end{aligned} \tag{52}$$

And substituting in (45) for $\frac{\partial L}{\partial\gamma_1}$ gives:

$$k_1 = \frac{(\kappa^2+\lambda)\chi\sigma\omega\psi + \kappa^2\frac{\nu\psi}{\kappa}}{\lambda\sigma\nu^2\psi^2}\frac{\partial\gamma_1}{\partial i_1}(-\beta((1+\zeta)E_1[L_{2,c}] - E_1[L_{2,nc}])) - \frac{E_1^{ps}\pi_2}{\nu\psi} - \frac{\xi_1^\pi}{\nu\psi} - \frac{\xi_1^s}{\psi} \tag{53}$$

Differentiating this with respect to ξ_1^B gives:

$$\frac{dk_1}{d\xi_1^B} = \frac{(\kappa^2+\lambda)\chi\sigma\omega\psi + \kappa^2\frac{\nu\psi}{\kappa}}{\lambda\sigma\nu^2\psi^2}(-\beta((1+\zeta)E_1[L_{2,c}] - E_1[L_{2,nc}]))\frac{d\frac{\partial\gamma_1}{\partial i_1}}{d\xi_1^B} \tag{54}$$

From (37)

$$\frac{\partial\gamma_1}{\partial i_1} = \frac{\exp(h_0 + h_B B_1 + h_k k_1)}{(1+\exp(h_0 + h_B B_1 + h_k k_1))^2}h_B\phi_i \tag{55}$$

Using the chain rule,

$$
\begin{aligned}
\frac{d\frac{\partial \gamma_1}{\partial i_1}}{d\xi_1^B} &= \left(\frac{\partial \frac{\partial \gamma_1}{\partial i_1}}{\partial B_1}\right)_{k_1} \left(\frac{\partial B_1}{\partial \xi_1^B}\right)_{i_1,k_1} + \left(\left(\frac{\partial \frac{\partial \gamma_1}{\partial i_1}}{\partial B_1}\right)_{k_1} \left(\left(\frac{\partial B_1}{\partial i_1}\right)_{k_1} \frac{di_1}{dk_1} + \left(\frac{\partial B_1}{\partial k_1}\right)_{i_1}\right) + \left(\frac{\partial \frac{\partial \gamma_1}{\partial i_1}}{\partial k_1}\right)_{B_1}\right) \frac{dk_1}{d\xi_1^B} \\
&= \left(\frac{\partial \frac{\partial \gamma_1}{\partial i_1}}{\partial B_1}\right)_{k_1} + \left(\left(\frac{\partial \frac{\partial \gamma_1}{\partial i_1}}{\partial B_1}\right)_{k_1} \left(\phi_i \frac{di_1}{dk_1} + \phi_s \psi\right) + \left(\frac{\partial \frac{\partial \gamma_1}{\partial i_1}}{\partial k_1}\right)_{B_1}\right) \frac{dk_1}{d\xi_1^B} \\
&= \frac{1 - \exp(h_0 + h_B B_1 + h_k k_1)}{(1 + \exp(h_0 + h_B B_1 + h_k k_1))^3} \left(h_B^2 \phi_i + \left(h_B^2 \phi_i \left(\phi_i \frac{di_1}{dk_1} + \phi_s \psi\right) + h_B h_k \phi_i\right) \frac{dk_1}{d\xi_1^B}\right)
\end{aligned} \tag{56}
$$

If we let $\alpha_1 \equiv \frac{(\kappa^2+\lambda)\chi\sigma\omega\psi + \kappa^2 \frac{\nu\psi}{\kappa}}{\lambda\sigma\nu^2\psi^2}$, $\alpha_2 \equiv -\beta((1+\zeta)E_1[L_{2,c}] - E_1[L_{2,nc}])$, $\alpha_3 \equiv \frac{1-\exp(h_0+h_B B_1+h_k k_1)}{(1+\exp(h_0+h_B B_1+h_k k_1))^3}$ and $\alpha_4 \equiv \left(h_B^2 \phi_i \left(\phi_i \frac{di_1}{dk_1} + \phi_s \psi\right) + h_B h_k \phi_i\right)$, then we can rewrite (54) as:

$$
\begin{aligned}
\frac{dk_1}{d\xi_1^B} &= \alpha_1 \alpha_2 \alpha_3 (h_B^2 \phi_i + \alpha_4 \frac{dk_1}{d\xi_1^B}) \\
&= \frac{h_B^2 \phi_i \alpha_1 \alpha_2 \alpha_3}{1 - \alpha_1 \alpha_2 \alpha_3 \alpha_4}
\end{aligned} \tag{57}
$$

Of these parameters, $\alpha_2 < 0$ and $\phi_i < 0$ given our assumptions that crises are costly and that a higher interest rate reduces real credit growth. We can also show that $\alpha_1 \alpha_4 > 0$. We can then distinguish between two cases, depending on whether α_3 is positive or negative. When it is positive, then $\frac{dk_1}{d\xi_1^B} > 0 \iff \alpha_1 > 0$. When it is negative, then if $\alpha_1 \alpha_2 \alpha_4$ is large enough in absolute terms, the same condition holds. But if the absolute value of $\alpha_1 \alpha_2 \alpha_4$ is small, then $\frac{dk_1}{d\xi_1^B} > 0 \iff \alpha_1 < 0$. We focus only on the first case, since $\alpha_3 > 0 \iff h_0 + h_B B_1 + h_k k_1 < 0 \iff \gamma_1 < 0.5$. And since Condition 1, which we assumed to ensure that the first order conditions define a global minimum for the loss function, implies that $\gamma_1 < 0.5$ at that minumum.

To show that $\alpha_1 \alpha_4 > 0$, we show that $\frac{\lambda \nu^2 \psi^2}{\kappa^2 + \lambda} \alpha_1 > \frac{\alpha_4}{(h_B \phi_i)^2} \iff \alpha_1 < 0$. Therefore α_1 and α_4 have the same sign, and their product is positive.

$$
\begin{aligned}
\alpha_1-\alpha_4 &= \frac{(\kappa^2+\lambda)\chi\sigma\omega\psi+\kappa^2\frac{\nu\psi}{\kappa}}{\lambda\sigma\nu^2\psi^2}-\left(h_B^2\phi_i\left(\phi_i\frac{di_1}{dk_1}+\phi_s\psi\right)+h_Bh_k\phi_i\right)\\
\iff \frac{\lambda\nu^2\psi^2}{\kappa^2+\lambda}\alpha_1-\frac{\alpha_4}{(h_B\phi_i)^2} &= \chi\omega\psi+\frac{\kappa^2}{\kappa^2+\lambda}\frac{\nu\psi}{\kappa}-\left(\frac{di_1}{dk_1}+\frac{h_B\phi_s\psi+h_k}{h_B\phi_i}\right)\\
&= \frac{h_B\phi_s\psi+h_k}{h_B\phi_i}-\omega\psi+\frac{\kappa^2}{\kappa^2+\lambda}\frac{\nu\psi}{\kappa\sigma}-\left(\frac{di_1}{dk_1}+\frac{h_B\phi_s\psi+h_k}{h_B\phi_i}\right)\\
&= \frac{\nu\psi}{\kappa\sigma}\left(\frac{\kappa^2}{\kappa^2+\lambda}-\frac{\kappa^2}{\kappa^2+\overline{\lambda}}\right)\\
&= \frac{\nu\psi\kappa}{\sigma(\kappa^2+\lambda)}\left(\frac{\overline{\lambda}-\lambda}{\kappa^2+\overline{\lambda}}\right)\\
&= \frac{\nu\psi\kappa}{\sigma(\kappa^2+\lambda)}\left(\frac{\frac{\chi\sigma\omega\psi}{\frac{\nu\psi}{\kappa}+\chi\sigma\omega\psi}\lambda-\lambda}{\kappa^2+\frac{\chi\sigma\omega\psi}{\frac{\nu\psi}{\kappa}+\chi\sigma\omega\psi}\lambda}\right)\\
&= \frac{\nu\psi\kappa}{\sigma(\kappa^2+\lambda)}\left(\frac{-\lambda\frac{\nu\psi}{\kappa}}{(\kappa^2+\lambda)\chi\sigma\omega\psi+\kappa^2\frac{\nu\psi}{\kappa}}\right)=\frac{-1}{\sigma^2(\kappa^2+\lambda)\alpha_1}
\end{aligned}
\tag{58}
$$

The final term is positive if and only if $\alpha_1<0$. Therefore $\alpha_1<0 \iff \frac{\lambda\nu^2\psi^2}{\kappa^2+\lambda}\alpha_1<0 \iff \frac{\alpha_4}{(h_B\phi_i)^2}<0 \iff \alpha_4<0$, so $\alpha_1\alpha_4>0$. Finally, given our sufficient condition that $\alpha_3>0$, $\frac{dk_1}{d\xi_1^B}>0 \iff \alpha_1>0$. Or equivalently:

$$
\begin{aligned}
&\frac{(\kappa^2+\lambda)\chi\sigma\omega\psi+\kappa^2\frac{\nu\psi}{\kappa}}{\lambda\sigma\nu^2\psi^2}>0\\
\iff &\frac{\frac{\partial\gamma_1}{\partial k_1}}{\frac{\partial\gamma_1}{\partial i_1}}>(\sigma\omega\psi-\nu\psi\frac{\kappa}{\kappa^2+\lambda})\sigma^{-1}\\
\iff &\frac{\frac{\partial\gamma_1}{\partial k_1}}{\frac{\partial\gamma_1}{\partial i_1}}\frac{\sigma}{(\sigma\omega\psi+\frac{\kappa^2}{\lambda+\kappa^2}\frac{\nu\psi}{\kappa})}>1
\end{aligned}
\tag{59}
$$

If this condition holds, the CCyB tightens in response to a positive credit shock. If not, then it loosens, and since the instruments are therefore substitutes, monetary policy tightens. This condition also motivates a more general definition of comparative advantage than χ, given by X:

$$X \equiv \frac{\frac{\partial \gamma_1}{\partial k_1}}{\frac{\partial \gamma_1}{\partial i_1}} \frac{(\lambda \frac{\partial y_1}{\partial i_1} + \kappa \frac{\partial \pi_1}{\partial i_1})}{(\lambda \frac{\partial y_1}{\partial k_1} + \kappa \frac{\partial \pi_1}{\partial k_1})} - 1 \tag{60}$$

$$= \frac{\frac{\partial \gamma_1}{\partial k_1}}{\frac{\partial \gamma_1}{\partial i_1}} \frac{\sigma}{(\sigma \omega \psi + \frac{\kappa^2}{\lambda + \kappa^2} \frac{\nu \psi}{\kappa})} - 1$$

This defines comparative advantage using the weighted average of each instrument's effects on both monetary goals, rather than just on aggregate demand.

B. Robustness

Many of the parameters we use to calibrate our model are highly uncertain. Table 7 explores how sensitive the summary statistics in our benchmark model are to varying some of those parameters. As in Tables 4 and 6 in the main text, we examine the model first in response to credit shocks only, then in a full stochastic simulation of the model. For all of the simulations, we set the policymaker's preference parameter for financial stability, as $\zeta = 0$.

The results are particularly sensitive to the key parameter that determines the cost of using the CCyB, ν, its effect on aggregate supply. Rows (ii) and (x) show the results with a smaller supply cost of $\nu = 0.05$, which implies that a 1pp increase in the CCyB reduces potential supply by 0.01%, equal to the lower end of the range reported in Brooke et al. (2015). Compared to the benchmark calibration of $\nu = 0.4$ (repeated for convience in rows (i) and (ix)), a smaller supply cost means the policymaker can achieve much improved outcomes: the median crisis probability is reduced from around 0.75% to around 0.05%, largely because the CCyB can be set higher on average at little extra cost. Policy also optimally responds more to shocks: in the full simulation the standard deviation of the CCyB is 3.8pp relative to 2.2pp in the benchmark calibration.

Rows (iii) and (xi) show the results with a higher supply cost of $\nu = 1$, implying that a 1pp increase in the CCyB reduces potential output by 0.2%, around twice as high as the median estimate reported in BCBS (2010b), though lower than the largest estimate reported there. In this case, the variances of output and inflation are higher than the benchmark, and the median crisis probability is around twice as high. The standard deviation of the policy instruments is similar to the benchmark calibration, but differently, the direction of interest rates is reversed in response to a credit shock.

Table 7: *Macroeconomic outcomes under different calibrations*

Case	SD(y_1)	SD(π_1)	SD(B_1)	median(γ_1)	SD(i_1)	SD(k_1)	$E(L)$
Simulation using credit shocks only							
(i) Benchmark calibration	0.11	0.005	5.3	0.77	0.11	1.45	1.37
(ii) Smaller supply cost of CCyB ($\nu = 0.05$)	0.02	0.001	5.1	0.04	0.41	2.22	0.14
(iii) Larger supply cost of CCyB ($\nu = 1$)	0.16	0.007	5.4	1.60	0.10	0.82	2.43
(iv) Larger interest elasticity of credit ($\phi_i = -18$)	0.13	0.003	5.8	0.95	0.11	1.62	1.61
(v) Zero spread elasticity of credit ($\phi_s = 0$)	0.12	0.006	5.9	0.95	0.12	1.63	1.61
(vi) Larger spread elasticity of credit ($\phi_s = -45$)	0.06	0.003	3.3	0.29	0.06	0.83	0.64
(vii) No resilience effect of the CCyB ($h_k = 0$)	0.14	0.006	5.2	2.18	0.13	1.77	3.25
(viii) Larger resilience effect of the CCyB ($h_k = -50$)	0.08	0.004	5.4	0.42	0.08	1.03	0.86
Simulation using all shocks							
(ix) Benchmark calibration	0.17	0.008	5.4	0.74	2.05	2.20	1.53
(x) Smaller supply cost of CCyB ($\nu = 0.05$)	0.08	0.004	5.4	0.05	2.20	3.80	0.19
(xi) Larger supply cost of CCyB ($\nu = 1$)	0.31	0.014	5.6	1.38	2.06	1.95	3.14
(xii) Larger interest elasticity of credit ($\phi_i = -18$)	0.27	0.007	13.5	0.97	2.14	3.32	5.47
(xiii) Zero spread elasticity of credit ($\phi_s = 0$)	0.18	0.009	5.9	0.92	2.05	2.23	1.81
(xiv) Larger spread elasticity of credit ($\phi_s = -45$)	0.13	0.006	5.4	0.27	2.04	2.21	1.04
(xv) No resilience effect of the CCyB ($h_k = 0$)	0.15	0.006	5.4	2.30	2.04	2.84	3.38
(xvi) Larger resilience effect of the CCyB ($h_k = -50$)	0.16	0.008	5.5	0.42	2.04	1.76	1.05

Notes. The table presents results obtained by running a stochastic simulation of the benchmark model described in Section 2. For each simulation, a single parameter (reported in the table) is changed from the benchmark calibration of Table 1. For all simulations $\zeta = 0$. The standard deviations of output (y_1), inflation (π_1), credit growth (B_1), the interest rate (i_1) and the CCyB (k_1) are reported in terms of annual percentage points; the median crisis probability (γ_1) is reported as an annual percentage rate; expected losses are reported as a per cent of losses incurred in the event of a financial crisis occuring in period 2. Results are reported for two alternative values of ζ, the relative weight placed on stabilising the crisis probability in the loss function. Expected losses are shown as a per cent of losses incurred in the event of a crisis also assuming that $\zeta = 0$, $L_{2,c}|\zeta = 0$.

Since the supply effect of the CCyB is larger than the demand effect (see Table 5), interest rates and the CCyB will both rise in response to a positive credit shock and be cut in response to a negative one. Taking all of these results together, there are striking differences in optimal policy settings over a plausible set of values for ν. For policymaking purposes, coming up with robust estimates of this cost should be a key priority.

Optimal policy is generally less sensitive to changes in the elasticity of credit to credit spreads or interest rates. In response to credit shocks, the standard deviation of the CCyB is only slightly higher when credit is made more senstive to interest rates than to credit spreads, either by increasing the interest elasticity of credit (row (iv)), or switching off the transmission from the CCyB to credit (row (v)). The standard devation of interest rates is almost unchanged. Intuitively, the small differences are because it is mainly the resilience channel of the CCyB that provides it with a large comparative advantage in reducing the crisis probability, and varying the relative effects of the two policies on credit does not fundamentally alter this. One aspect of the results which is significantly affected is the standard deviation of credit in the full stochastic simulation when it is highly interest elastic (row (xii)). Credit growth is more volatile (13.5pp rather than 5.4pp), because it is more affected by the volatility of interest rates in response to demand shocks. The median crisis probability remains low, however, because increased credit volatility is matched by a more responsive CCyB (a standard deviation of 3.32pp compared to 2.20pp in the benchmark).

The results are somewhat more affected if the credit has a very large spread elasticity. In rows (vi) and (xiv) it is set almost 8 times bigger than the benchmark calibration. The median crisis probability falls to around one-third of the rate as a result. In the full stochastic simulation, the standard deviation of both policy instruments is almost unchanged (row (xiv)). But this result masks a difference in transmission: with a higher spread elasticity, the CCyB is more effective at reducing the crisis probability, so needs to respond less to credit shocks (row (vi)). This is offset in the full simulation by a need to respond more to spreads shocks, since these now have a larger effect on credit growth and the crisis probability.

The findings are also sensitive to the size of the resilience benefits from using the CCyB, which is important given the large uncertainty surrounding our estimates of this effect (reported in Table 3 in the main text). To illustate this, rows (vii) and (xv) of Table 7 repeat the simulations with the resilience parameter set as $h_k = 0$; rows (viii) and (xvi) set $h_k = -50$. The values selected roughly correspond to two standard errors in either direction around our benchmark estimate ($h_k = -27.8$). With no resilience effect of the CCyB, the instrument must be varied more aggressively in response to credit shocks – it has a standard deviation of 1.77pp compared to 1.45pp in the benchmark calibration. This only reduces the standard deviation of credit growth by 0.1pp however, such that the median crisis probability is around 1.5pp higher and expected losses more than double those in the benchmark calibration. The instrument is not varied any more aggressively because doing so would create excessive output and inflation losses. Similar results hold in the full stochastic simulation. With a larger resilience effect, we find the converse is also true – when the CCyB is more effective it is varied less. The CCyB and interest rate variances are lower, because despite a higher credit volatility, a larger resilience effect means that the crisis probability can be lowered significantly (0.42% versus 0.74% in the full stochastic simulation), without increasing the volatility of period 1 inflation or output.