Targeting Financial Stability: Macroprudential or Monetary Policy?*

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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

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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, and a risk-taking channel of monetary policy affect our results.

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1. Introduction

The development of macroprudential policy frameworks over the past decade has been one of the major policy responses to the global financial crisis. Some macroprudential policies 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 latter are designed to address the strong collective tendency for financial institutions, companies, and households to overexpose themselves to risk in the upswing of a credit cycle and to become overly risk averse in a downswing.[1] In the face of such tendencies, macroprudential tools, such as time-varying capital requirements or limits on loan-to-value ratios in mortgage markets, can help to reduce the likelihood of financial crises and improve welfare (see, for example, Brunnermeier and Sannikov 2014; Farhi and Werning 2016). The countercyclical capital buffer (CCyB), adopted under Basel III, is an example in the first class of tools; it enables authorities to adjust banks’ risk-weighted capital requirements as cyclical systemic risks evolve.[2]

Alongside the development of macroprudential policy regimes, there has been a sharp debate on the role of monetary policy in

[1] This procyclicality may reflect a range of sources, including myopia about risk (see, for example, Gennaioli, Shleifer, and Vishny 2012), herding in financial markets (Gennaioli, Shleifer, and Vishny 2012; Aikman, Nelson and Tanaka 2015), moral hazard (Farhi and Tirole 2012), or a failure to internalize fire-sale and aggregate demand externalities which may arise during crises (Lorenzoni 2008; Korinek and Simsek 2016; Bianchi and Mendoza 2018). It may also be amplified endogenously, as easing collateral constraints during credit booms or deteriorating lending standards incentivize higher leverage and greater short-term borrowing (Minsky 1982; Kiyotaki and Moore 1997; Geanakoplos 2003, 2010; Gertler and Kiyotaki 2015).

[2] See Basel Committee on Banking Supervision (2010c) and Bank of England (2016) for detailed summaries of how this tool operates.

"leaning against the wind" to tackle buildups in systemic risk. Some policymakers argued before the crisis that monetary policy should be used to tackle financial imbalances (Borio and Lowe 2002; White 2006) and continue to do so (Borio 2016). Proponents of this approach argue that low interest rates encourage excessive risk-taking. They contend that only tighter monetary policy during a credit boom "gets in all the cracks" to dampen risk-taking across the whole financial system, including market-based finance (Stein 2013), though many argue for a combination of monetary and macroprudential policies (e.g., Shin 2015). By contrast, others contend that cost-benefit considerations imply little or no role for monetary policy in "leaning against the wind" (Svensson 2017), or that it should be used only as a "last line of defense" once macroprudential policies have been found wanting (Kohn 2015).

These issues highlight the importance of incorporating macroprudential instruments into macroeconomic modeling frameworks to help answer key policy strategy and design questions. These questions include the following: What amplitude should we expect fluctuations in the CCyB to have to manage financial stability risks? Under which conditions and shocks are monetary and macroprudential policies likely to be substitutes or complements? And how do the effective lower bound for monetary policy and the presence of market-based finance affect these results?

This paper tackles such questions by developing a novel, parsimonious model to analyze how macroprudential regulators should integrate the CCyB alongside monetary policy in a macroeconomic policy setup. It is calibrated to match some salient moments of the U.K. data. We focus on the CCyB, as it is the only macroprudential tool with a concrete, common international implementation framework, while recognizing the potential importance of modeling other macroprudential tools (see Aikman, Haldane, and Kapadia 2013) in future work.[3] The model features two periods. Aggregate demand in

[3]Other macroprudential tools in use include those that constrain bank balance sheets, such as reserve requirements, and those that focus on borrowers, such as loan-to-income and debt service limits. A formal analysis of such tools would need to take account of their different impact on balance sheet resilience and credit conditions vis-à-vis the CCyB. Some of these tools, such as reserve requirements, are also much less widely deployed in economies where the interest rate is the primary instrument of monetary policy, which are the focus of this paper.

period 1 is determined by an "IS" curve and inflation by a Phillips curve, with the credit spread entering both relationships (in line with Cúrdia and Woodford 2010). We depart from the New Keynesian tradition (Clarida, Galí, and Gertler 1999) by including the possibility that a credit boom will lead to a financial crisis in the second period, following earlier work by Ajello et al. (2019).

We depart from Ajello et al. (2019) by allowing the policymaker to lean against the credit boom via both traditional monetary policy and the CCyB. Higher interest rates reduce credit growth and hence reduce the probability of a crisis in period 2, but this comes at the cost of lower current activity. An increase in the CCyB increases banks' overall funding costs, which banks in turn pass on to borrowers via higher loan spreads, also reducing credit growth. While this channel features in most existing analyses of the CCyB (see for instance Angelini, Neri, and Panetta 2014), it contrasts with the mechanism emphasized by the CCyB-setting authorities themselves, who instead focus on the resilience-enhancing role of this tool (see Bank of England 2016; Federal Reserve Board 2016). 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-center in our model: deploying the CCyB directly 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 minimize a loss function.[4] The loss function is another novelty of our model. It encompasses the traditional goals of limiting inflation and output volatility, but supplements this by allowing for additional financial stability considerations that manifest as a desire to reduce the probability and/or severity of the crisis state. This may reflect a desire to avoid direct fiscal or distributional costs from financial crises; it is also consistent with policy-setting in the presence of hysteresis effects from financial

[4]The benefits of explicitly coordinating these policy levers are very small in our setting: similar economic performance can be achieved by a regime in which the monetary authority targets inflation and output volatility at a two- to three-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.

crises. This description of preferences provides a better description, we argue, of central banks' post-crisis mandates than the ubiquitous quadratic loss function.

Our model delivers several sharp insights. First, deploying the CCyB improves outcomes significantly relative to when the interest rate is the only available tool. This reflects the logic of the Tinbergen principle that to achieve two targets (price and financial stability), two instruments are superior. It reinforces the rationale for having expanded policy toolkits to include the CCyB, and it provides grounding for the view that macroprudential tools complement monetary policy by reducing macroeconomic tail risks.

Second, we isolate the conditions under which it is appropriate to vary the banking system's capital buffer actively over the cycle. This is the case if applying the CCyB generates a sufficiently large adverse impact on potential supply by reducing bank credit to fund real investment. Otherwise, it is better to maintain a high, constant capital buffer throughout non-crisis phases of the financial cycle. Under our preferred 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 percent is required to stabilize the crisis probability when credit growth persistently reaches around 12.5 percent per year. And, in a full stochastic simulation of the model, the standard deviation of the CCyB is around 2.2 percentage points. This contrasts with a CCyB ceiling of 2.5 percent in some jurisdictions.[5]

A third notable finding is that when faced with a credit boom, it is appropriate to tighten the CCyB and to cushion its macroeconomic impact by cutting interest rates—that is, the CCyB and monetary policy are substitutes. We show that the appropriate policy response is governed by two parameter conditions in the model: the first summarizes the relative impact of the CCyB on aggregate demand and potential supply; the second summarizes the relative comparative advantage of the CCyB vis-à-vis monetary policy in tackling credit booms. Under our benchmark calibration, the comparative advantage in reducing crisis risk lies decisively with the CCyB, and the aggregate demand effects of this tool outweigh its

[5]For example, under the Federal Reserve Board's framework for implementing the CCyB, there is an explicit cap on the size of the buffer of 2.5 percent.

impact on potential supply, making looser monetary policy appropriate when the CCyB is tightened. There are, however, parameter configurations where the instruments are complements, though these cases are less plausible.

More generally, we show that complementarity or substitutability of macroprudential and monetary policy depends crucially on the type of shocks hitting the economy. It is plausible for the instruments to be adjusted in the same (tightening) direction when the economy faces a combined credit boom and positive aggregate demand shock, for instance. This scenario may be viewed as reflecting a positive shock to sentiment, or "animal spirits," which manifests itself in both the credit and the business cycle, e.g., as in the late-1980s boom in the United Kingdom. Similarly, faced with an adverse shock to bank credit supply, which leads to tighter credit conditions and lower aggregate demand and inflation, our model suggests that 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 jeopardizing future resilience while threats might still 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. We find that our baseline findings continue to hold but are attenuated somewhat quantitatively. First, the CCyB should probably be used less aggressively when monetary policy is constrained at the effective (zero) lower bound. With monetary policy unable to cushion its near-term macroeconomic impact, the policymaker uses the CCyB less actively and tolerates a higher crisis probability at the margin, though this effect may be offset if it is additionally assumed that the costs of financial crises are greater when interest rates are constrained at the effective lower bound. Second, CCyB policy should also be less active when there is a large market-based finance sector. Incorporating such a sector that is not subject to the CCyB both directly reduces the effectiveness of the CCyB and induces "leakages" through which credit migrates from banks to other financing sources outside its scope following a tightening of the CCyB. Intuitively, both factors diminish the effectiveness of the CCyB. Finally, if there is a "risk-taking channel" of monetary policy (Adrian and Shin 2010a; Borio and Zhu 2012), whereby low interest rates trigger excessive risk-taking by banks, this reduces the appeal of the policymaker's benchmark strategy, since it becomes less effective to loosen monetary policy in an attempt to cushion the macroeconomic effects of CCyB hikes.

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 Angeloni and Faia (2013), Angelini, Neri, and Panetta (2014), 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 setup to examine jointly Ramsey-optimal policy, as do De Paoli and Paustian (2017), who also analyze non-cooperative equilibria. But this line of research tends to focus on individual frictions and specific variables such as leverage and risk-taking, thus limiting its wider applicability to analyzing a range of trade-offs and practical, real-world challenges facing policymakers.

Our paper also 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 2011; 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 (Filardo and Rungcharoenkitkul 2016; Svensson 2017; Gourio, Kashyap, and Sim 2018; Ajello et al. 2019). But all these contributions focus on monetary policy acting to achieve financial stability in isolation, excluding an explicit role for macroprudential policy. Fahr and Fell (2017) are an exception in considering macroprudential policies in this type of setup. But they take a conceptual rather than quantitative approach, focusing on deriving conditions for assigning monetary and macroprudential policies to price and financial stability objectives.

The remainder of the paper is organized 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. Modeling 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. (2019) 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. In the first period, output, inflation, credit growth, loan spreads, and the probability of a financial crisis are 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 in the second period depend on whether or not a financial crisis occurs.

Aggregate demand and inflation in period 1 are determined by[6]

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

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

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

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

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. There are two shocks: ξ_1^y is a demand or consumption preference shock and ξ_1^π is a cost-push or markup shock. E_1^{ps} denote the private sector's expectations of period 2. In period 2, output 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. Inflation in period 2 is $\pi_{2,nc}$ and $\pi_{2,c}$ in each respective state.

This structure incorporates two departures from the canonical New Keynesian model (Clarida, Galí, and Gertler 1999). 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, (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' labor 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 labor productivity. They also increase the cost of financing firms' working capital needs, as in Carlstrom, Fuerst, and Paustian (2010).[7]

Second, we allow that the private sector's expectations of period 2 outcomes may be myopic and ignore potential links between credit growth and the possibility of a financial crisis, consistent with theories of neglected tail risk (Gennaioli, Shleifer, and Vishny 2015)

[7]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 unless the channel is particularly large, it does not alter our qualitative results. As long as the net effect of a monetary policy tightening is still to reduce inflation, rather than increase it, the optimal response to a credit shock and the conditions governing instrument substitutability are little changed.

or irrational exuberance (Shiller 2000).[8] In particular, we assume that the private sector's period 2 expectations of inflation and output are exogenous, and calibrate the model so that they are equal to their (correct) expectation of the outturns conditional on a crisis not occurring:

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

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

This assumption is consistent with the empirical evidence mentioned by Ajello et al. (2019), who note that predictions by the U.S. Survey of Professional Forecasters placed almost no weight at all on large falls in gross domestic product (GDP) or inflation in the run-up to the financial crisis. We show in Appendix A that this non-rationality assumption is not crucial to our results. With rational expectations, agents in our model reduce spending in response to any increase in the probability of a financial crisis. For example, absent any offsetting policy response, a positive credit quantity shock would increase the crisis probability and lower agents' mean expectation of period 2 output. Consumption-smoothing behavior would then lead them to also cut demand in period 1. We discuss in Section 4 the main implication of assuming, instead of an exogenous probability, that agents correctly perceive the relationships between credit growth, the CCyB, and crises. We also relate this to an intermediate case where agents correctly perceive the relationship between credit, the CCyB, and crises on average, but are unable to distinguish between good and bad credit booms, as in Gorton and Ordoñez (2014, 2019).[9]

[8] Bordalo, Gannaioli, and Shleifer (2018) present a model in which agents' beliefs about future states are based on Kahneman and Tversky's representativeness heuristic, such that they overweight future outcomes that become more likely given news in the data. In the model, agents make predictable forecast errors and neglect tail risk during periods when volatility is low.

[9] Ajello et al. (2019) allow the private sector to place a small positive, *exogenous* probability on a crisis occurring. In Appendix A, we solve the model for this more general case. We show that different exogenous probabilities have little qualitative effect on our results, and that for one parameterization of the credit growth equation, (5), also leave them quantitatively unchanged. Intuitively, this occurs because in equilibrium, the policymaker is able to set period 1 policy to offset most or all of the impact of different period 2 expectations on the economy.

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

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

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

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

where B_1 is defined as real private non-financial-sector credit growth; k_1 is the setting of the CCyB in period 1, which must be greater than or equal to zero; and γ_1 is the probability of a financial crisis occurring between period 1 and period 2.

Real credit growth depends negatively ($\phi_s, \phi_i < 0$) on interest rates and credit spreads. A constant term, ϕ_0, captures the steady-state rate of credit growth, while ξ_1^B is a shock to the demand for credit. Banks are willing to supply credit at a spread that depends on the capital requirement they face (discussed below) and an exogenous shock ξ_1^s. Given the simple structure of our model, this latter shock admits several alternative interpretations.[10] The shocks ξ_1^B and ξ_1^s may be correlated with each other and with the demand and supply shocks ξ_1^y and ξ_1^π. In this way, although credit growth does not directly affect output and inflation via the IS and Phillips curves, such effects may be replicated by allowing for correlated shocks, as discussed further in Section 4.2.

For example, we could assume that changes in the growth rate of credit enter the IS curve, thus influencing the level of aggregate demand directly, with the effect governed by a parameter q, such that

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

[10] For instance, it could serve as a shortcut to capture the impact of capital losses in the banking system, which would manifest as restrictions to credit supply and hence wider lending spreads. It could also reflect a reassessment by banks of prospective credit losses on their exposures and hence the compensation they require for bearing this risk—such a reassessment could be warranted, in which case presumably correlated with current and expected aggregate demand, or it could instead reflect a shift in banks' risk appetite.

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

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

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

With parameters suitably redefined, we could alternatively replicate this model using the benchmark model and assuming a more positive correlation between demand and credit shocks. By initially focusing on the case where these shocks are uncorrelated, we are able to describe how policy should respond to the case where the credit and business cycles are particularly misaligned, which is where the use of a macroprudential policy tool is likely to be most advantageous. It also describes the scenario in the early to mid-2000s, when credit was growing strongly but inflation remained close to target.

The CCyB influences the likelihood of a financial crisis via two channels. First, all else equal, an increase in the banking system's capital ratio reduces the probability of a crisis directly ($h_k < 0$ 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.[11] 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 emphasize the role of bank capital in incentivizing 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.[12] Consistent with empirical findings (e.g., Borio and

[11]We have also explored how our results are affected if bank capital affects the severity of crises but not their probability, consistent with empirical evidence provided by Jordà et al. (2020). Our main results are broadly unchanged. In either case, higher bank capital reduces the expected policymaker loss from financial crises, irrespective of whether the reduced loss comes from a lower crisis probability (and an exogenous severity) or a lower crisis severity (and an exogenous probability).

[12]This implicitly assumes that the Modigliani-Miller conditions do not apply in full—for example, due to tax distortions or bankruptcy costs. Indeed the departures are likely to be particularly large for banks, given that a large proportion

Lowe 2002, Schularick and Taylor 2012), we assume that an increase in credit growth leads to a higher crisis probability ($h_B > 0$ in Equation (7)). This could reflect the impact of an economy becoming more leveraged and hence vulnerable to adverse shocks; it could also capture the deterioration in credit quality that tends to accompany lending booms. Of course, not all credit booms end in crises: Dell'Ariccia, Laeven, and Suarez (2017) report that only one-third of credit booms across their sample result in full-blown crises.[13] Reflecting this, we interpret h_B as the probability the policymaker attaches to the boom ending in a crisis. In our baseline model, private-sector agents assume $h_B = 0$ (as well as $h_k = 0$); that is, they do not update their estimates of crisis risk during credit booms.[14]

Banks, we assume, are able to pass on some of the increased costs they face from a higher CCyB, 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).[15] The CCyB can influence the risk environment facing banks through this "leaning" channel: activating the CCyB tempers the buildup in credit growth and hence reduces the likelihood of a financial crisis. Note also that the CCyB will therefore have knock-on effects on both aggregate demand and supply via the IS curve (1) and Phillips curve (2).

It is implicit in this setup that regulators determine the banking system's capital ratio, and thus leverage, in period 1 via setting the CCyB. This is consistent with empirical evidence that U.K. banks have tended to adjust their capital ratios one-for-one with

of their funding is via deposits, which offer liquidity services to households and firms. Moreover, historically, market perceptions that debt holders of large banks would be unlikely to suffer losses because such banks would not be allowed to fail made debt funding costs relatively insensitive to leverage.

[13]Gorton and Ordoñez (2019) show that there is a difference in productivity growth over credit booms that end in crises and those that do not.

[14]We show the implications of relaxing this assumption in Appendix A.

[15]One could also posit a direct relationship between monetary policy and credit spreads, as in some formulations of the risk-taking channel of monetary policy. The only qualitative effect of doing so is to introduce a cost channel, which has little impact on our results. The other, quantitative effects can be easily explored by increasing the interest elasticities of credit, which we do in Appendix B, and of demand. We explore an alternative way of introducing a risk-taking channel in Section 5.4.

a lag following changes in their requirements (Ediz, Michael, and Perraudin 1998; Bridges et al. 2014). This assumption implies that the cyclical dynamics of bank leverage ratios are governed by regulators rather than by banks' own objective functions, which are likely to have played a role in driving observed leverage dynamics in the past (Adrian and Shin 2010b). In periods of exuberance, this assumption is unlikely to be problematic. In particular, even if banks were to restrain their risk by adjusting their own leverage countercyclically (as implied by the model of Gertler and Kiyotaki 2015, for instance), this is unlikely to mitigate all systemic risks, and while the CCyB might then be a *relatively* less important policy instrument, it could and may still need to be set high enough to override what banks would otherwise choose. A greater challenge is understanding the likely transmission of releasing the CCyB in a bust. It is plausible that some banks will face market pressure to solidify their solvency positions in such states, consistent with models that feature value-at-risk constraints (e.g., Adrian and Shin 2013) and evidence reported by Adrian and Shin (2010b) that investment banks' leverage is highly procyclical. At the same time, the intention of the Basel III framework—including the CCyB—is to ensure that capital buffers are sufficiently high when crises hit, and much higher than banks' own optimal capital buffers, thus implying that there should be sufficient space for a release of the CCyB during periods of stress to ease the (binding) regulatory constraint facing banks. This effectiveness or otherwise of releasing the CCyB would show up in the cost of financial crises.

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 buildup 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.

It is instructive to compare our reduced-form specification of the financial system with models that provide more formal microfoundations for the behavior of banks. A prominent example here is the Gertler and Kiyotaki (2015) model (henceforth GK), which embeds a microfounded bank run in a dynamic stochastic general equilibrium setting. In this model, banks face an incentive constraint, which limits the leverage they can obtain from depositors. Bank runs occur when depositors rationally surmise that the bank would be insolvent if its assets were valued at liquidation prices. The key determinants of bank runs are therefore (i) the return on the bank's assets under liquidation, which in turn depends on their underlying profitability and the fire-sale discount required to induce non-specialist investors to clear the market, and (ii) the bank's leverage ratio, which determines the scale of the funding run and the sensitivity of the bank's equity to asset return shocks. A key result is that there exists a "tipping point" beyond which shocks that increase leverage or reduce asset returns may cause a run.

While it lacks the richness afforded by these microfoundations, the reduced-form crisis probability function we employ in Equation (7) nevertheless shares some similarities with GK. In our setup, as in GK, the probability of a future banking crisis is increasing in the bank's leverage. Crisis risk in our model is also increasing in credit growth. Although there is no specific role for this factor in GK, one interpretation is to view credit growth as a proxy for lending standards: it is well-known that periods of rapid credit growth typically go hand-in-hand with deteriorating lending standards (Dell'Ariccia, Laeven, and Suarez 2017). Viewed through the lens of GK, falling lending standards would lead to higher credit losses and hence lower future asset returns, pushing the bank closer to the bank run threshold.

Our work also relates to the literature on endogenous financial cycles. In Hyman Minsky's seminal financial-instability hypothesis (Minsky 1982), even an initially robust financial system will eventually become fragile. This occurs as agents are incentivized to take on more debt over time and shift towards less stable funding arrangements with lower financing costs—particularly so after a run of good or tranquil years, which lenders and borrowers tend to extrapolate forward. In Geanakoplos (2003, 2010) the borrowing capacity of agents is constrained by the availability of collateral. In a boom where volatility remains low for an extended period, haircuts fall and borrowing capacity rises, pushing up asset prices and leverage, but also making the financial system vulnerable to an adverse shock.[16] While our model lacks the richness of these accounts, the inclusion

[16]See also Kiyotaki and Moore (1997), who present a model in which the combination of collateral constraints and investment adjustment costs leads to cycles in credit and asset prices.

of credit growth in our crisis probability function (7) is intended to capture similar mechanisms in a shorthand way: rapid credit growth is a proxy for declining lending standards, rising leverage, and riskier funding—factors which all make the system more prone to a crisis.

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 minimize an overall loss function comprising both monetary and financial stability objectives. This allows us to analyze the normative question of how policy should be set to meet given objectives, free of institutional constraints. It also closely approximates the institutional setup of the Bank of England: the Monetary Policy and Financial Policy Committees have overlapping objectives, overlapping membership, and common information sets.[17] We compare the performance of this setup to a decentralized 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

[17]The objective of the Bank of England's Monetary Policy Committee is to maintain price stability and, subject to that, to support the Government's economic objectives including those for growth and employment; the objective of the Financial Policy Committee is to protect and enhance the stability of the UK's financial system and, subject to that, 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.

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 their target levels, as captured by the first two terms in inflation and output. But in addition, we introduce a term, parameterized by ζ, which allows for "overweighting" losses suffered in the event of a financial crisis. When $\zeta > 0$, financial stability objectives lead the policymaker to attempt to minimize the probability of a financial crisis to a greater degree than quadratic expected losses alone would imply is optimal. The greater is ζ, the more the central bank's objectives are skewed in the direction of crisis avoidance relative to symmetrically stabilizing 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, following the financial crisis, many central banks have been 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 UK's 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 crises. 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.[18]

The policy problem facing the central bank is therefore to choose an interest rate and CCyB rate in period 1 to minimize 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 three years. This allows us to capture the notion that financial system vulnerabilities build up gradually in response to prolonged credit

[18] 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:

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

to give

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

where $\overline{\zeta} \equiv \zeta + (1+\zeta)\beta p^2$ is the additional weight placed on avoiding crises, which includes 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 ($\overline{\zeta} > 0 \iff p > 0$).

Table 1. Benchmark Parameter Values

Parameter	Description	Parameter	Notes
	Standard Parameters		
β	Discount Factor	0.97	Matches r* = 1%
σ	Interest Rate Sensitivity of Output	0.6	Burgess et al. (2013)
κ	Slope of the Phillips Curve	1	Burgess et al. (2013)
λ	Weight on Output Stabilization	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 (2010b), 1 pp CCyB Increases Loan Spread by 20 bps
ω	Effect of Spreads on the IS Curve	1	Cloyne et al. (2015)
v	Effect of Spreads on the Phillips Curve	0.4	Franklin, Rostom, and Thwaites (2020)
	Financial Conditions Equation		
ϕ_0	Average Real Credit Growth	0.21	U.K. 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	$-1.72 + 0.11h_k$	Estimated Using a Cross-Country Data Set
h_B	Sensitivity of Crisis Probability wrt Credit Growth, B	5.18	
h_k	Sensitivity of Crisis Probability wrt CCyB, k_1	–27.8	

(*continued*)

Table 1. (Continued)

Parameter	Description	Parameter	Notes
	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 U.K. Sample Data, 1977–2007
$SD(\xi_1^s)$	Standard Deviation of Credit Spread Shocks	0.006	Set to Match Standard Deviation of Annual Average of Major Six U.K. Banks' CDS Premia, 2005–17

Note: 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 percent, which are included via the constant term in the equation (h_0).

booms (Drehmann, Borio, and Tsatsaronis 2012; Aikman, Haldane, and Nelson 2015). 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. Three-year time periods therefore capture the interaction between tools in a more meaningful way. To allow our parameters on policy transmission to be easily compared with the existing literature, the calibration uses our three-year variables expressed in annualized terms. With the exception of the loss function, the model is linear, so this is a simple normalization. For the quadratic loss function, losses depend on the dynamic profiles of output and inflation. We assume that the cumulative output and inflation deviations from target—for example, from tighter monetary policy—are distributed evenly over each of the three years, even though policy may in reality have more potency in earlier quarters if prices become less sticky over time.

The model's standard macroeconomic parameters, i.e., those that govern the monetary policy transmission mechanism, are calibrated to be consistent with 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 three years reduces the level of GDP by an average of 0.6 percent over the period, while $\kappa = 1$ implies that a fall in GDP by 1 percent over the three-year period reduces annual inflation by an average of 1 percentage point.[19]

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 Basel Committee on Banking Supervision (2010b). We set ϕ_s, the sensitivity of credit growth to loan spreads,

[19]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. We view this as a pragmatic way of calibrating a persistent change in policy given the presence of the well-known forward-guidance puzzle in standard full-information rational expectations DSGE models used by many central banks. Burgess et al. (2013, Section 6.2.6) describes how a similar procedure was used to condition projections for GDP and inflation on a measure of market expectations of future interest rates for the Bank of England MPC's *Inflation Report* publication.

equal to –6, based on estimates from the model described in Cloyne et al. (2015).[20] This is four times as large as the effect of risk-free interest rates on credit growth from the same model. 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 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 (2010b), which was a reduction in the level of credit of 1.4 percent 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).[21] 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 (2020). This paper finds that each percentage-point fall in corporate lending after the 2008 financial crisis reduced both capital intensity and U.K. labor productivity by at least 0.3 percent. If we were to assume that falls in lending associated with a higher CCyB had proportionally similar effects on labor 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 the fall in U.K. labor productivity in recent years has been driven by the scale and nature of the financial crisis rather than being caused by lower corporate lending per se. By contrast, if the only channel affecting potential output in typical conditions is capital shallowing, then using the capital intensity estimate of 0.3 percent and the approximate share of capital in production of one-third would imply a fall in labor productivity and

[20]The estimates were made available to us by the authors.

[21]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.

potential output of 0.1 percent. 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.[22]

The parameters governing the crisis probability function are estimated using a cross-country panel data set; we estimate Equation (7) directly using the sample of countries and years for which both capital and credit data are available, summarized in Table 2.[23] These results are reported in Table 3. The magnitudes are comparable to the BCBS (2010a) meta-study, where starting at an average crisis probability of around 2 percent, increasing the TCE/RWA (tangible common equity/risk-weighted assets) ratio by 1 percentage point (pp) (from 9 percent to 10 percent) reduces the probability by 0.5 pp.

Figure 1 illustrates the relationship between credit growth, the CCyB, and the crisis probability implied by this equation. Evaluated at a CCyB of 0 percent, the sample average rate of real credit growth of 7 percent per year ($\phi_0 = 0.21$ – 21% over three years) and steady-state capital ratios of 11 percent, the annual crisis probability is around 2.4 percent. The estimated coefficients imply that an increase in credit growth of 1 pp to 8 percent per year would increase the annual probability of a crisis by around 0.4 pp, while, holding credit fixed, the direct impact of an increase in the CCyB of 1 pp reduces the crisis probability by nearly 0.6 pp per year. The

[22] Ajello et al. (2019) explore the effects of uncertainty on the setting of monetary policy. While modeling 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.

[23] The data set is from Bush, Guimarães, and Stremmel (2015) and we thank the authors for making it available to us. The broad empirical approach draws on Drehmann, Borio, and Tsatsaronis (2011) and Schularick and Taylor (2012). But the specification differs from the logit model estimated by Schularick and Taylor (2012) in two respects. First, and most importantly, we include the capital ratio of each country's banking system as an additional explanatory variable. Second, we consider three-year lags of annual credit growth rather than five-year lags.

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

estimated equation implies a peak U.K. annual crisis probability of 12 percent in 2008.

We assume that output in the event of a crisis contracts by an average of around 4 percent per year, roughly in line with the estimates reported in Brooke et al. (2015), which incorporate the effect of new resolution regimes in reducing the cost of crises.[24] We assume

[24]Specifically, we take the GDP loss in each of the first five years after a banking crisis in the subsample of countries with a fast and comprehensive resolution regime shown in Chart 6 of Brooke et al. (2015). The total quadratic loss is equivalent to 4.1 percent per year for each of our three-year time periods. We abstract from the possibility discussed by Svensson (2017) that crises may be more costly

Table 3. Logit Estimation for the Probability of Financial Crises

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

Note: Robust standard errors are shown in parentheses. Regression includes dummies for country fixed effects. These are set to zero for the United Kingdom 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 the euro-area banks reported in BCBS (2010a, Table A5.1). ***, **, and * denote significance at the 1 percent, 5 percent, and 10 percent level, respectively.

that inflation remains at target in the crisis state, reflecting the experience internationally following the 2008 crisis (Gilchrist et al. 2017). As we abstract from further shocks, the policymaker is able to achieve zero output and inflation gaps in period 2 if a crisis does not occur.

To aid intuition, Figure 2 compares the impact on key model variables of exogenous 100 basis point increases in the CCyB and the monetary policy rate. In short, the interest rate has a materially larger impact on aggregate demand and inflation; the CCyB

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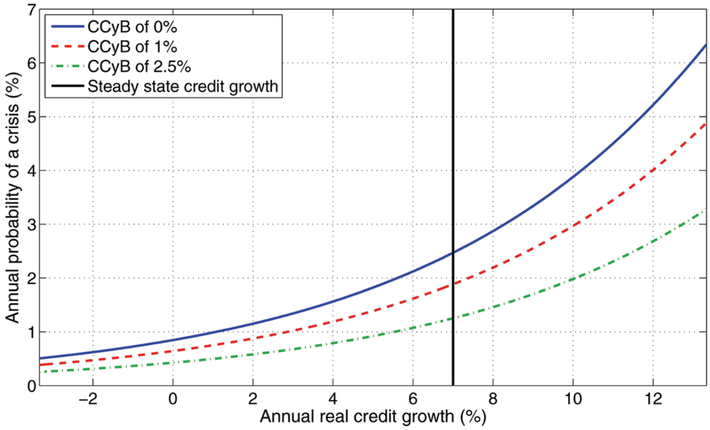
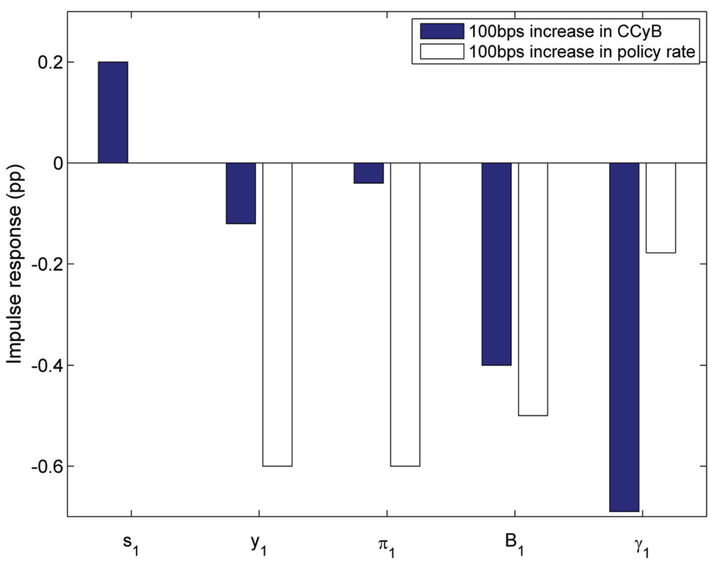
if the economy already has a negative output gap, but discuss this briefly in Section 4.2.

Figure 1. Crisis Probability and Credit Growth for Different Levels of the CCyB



Note: The figure plots the relationship between the financial crisis probability and credit growth in Equation (7) under the benchmark calibration for alternative values of the CCyB.

Figure 2. Impacts of 100 Basis Point Increases in the CCyB and Monetary Policy Rate



Note: 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).

has a far greater impact on the crisis probability; and these instruments have roughly equal effects on credit growth. In absolute terms, the dampening effect on credit growth from either instrument is not large: following a rise in the CCyB, only around 0.1 pp of the 0.7 pp fall in the crisis probability comes via the reduction in credit growth.

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 U.K. historical data, while the loan spread shock is set to match the standard deviation of average U.K. bank CDS spreads over the crisis period.

3. Main Results

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

$$\sigma(\kappa\pi_1 + \lambda y_1) = \frac{\partial\gamma_1}{\partial i_1}\frac{\partial L}{\partial\gamma_1}, \tag{11}$$

where $\frac{\partial\gamma_1}{\partial i_1}$ is the derivative of the crisis probability with respect to interest rates, and $\frac{\partial L}{\partial\gamma_1} = -\beta(\pi_{2,nc}^2 + \lambda y_{2,nc}^2) + \beta(1+\zeta)(\pi_{2,c}^2 + \lambda y_{2,c}^2)$ 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 intratemporal trade-off between stabilizing inflation and output in period 1 in the presence of cost-push shocks; second, an intertemporal trade-off between stabilizing output and inflation in period 1 and reducing the probability of a financial crisis, which, if it occurs, would depress output in period 2.

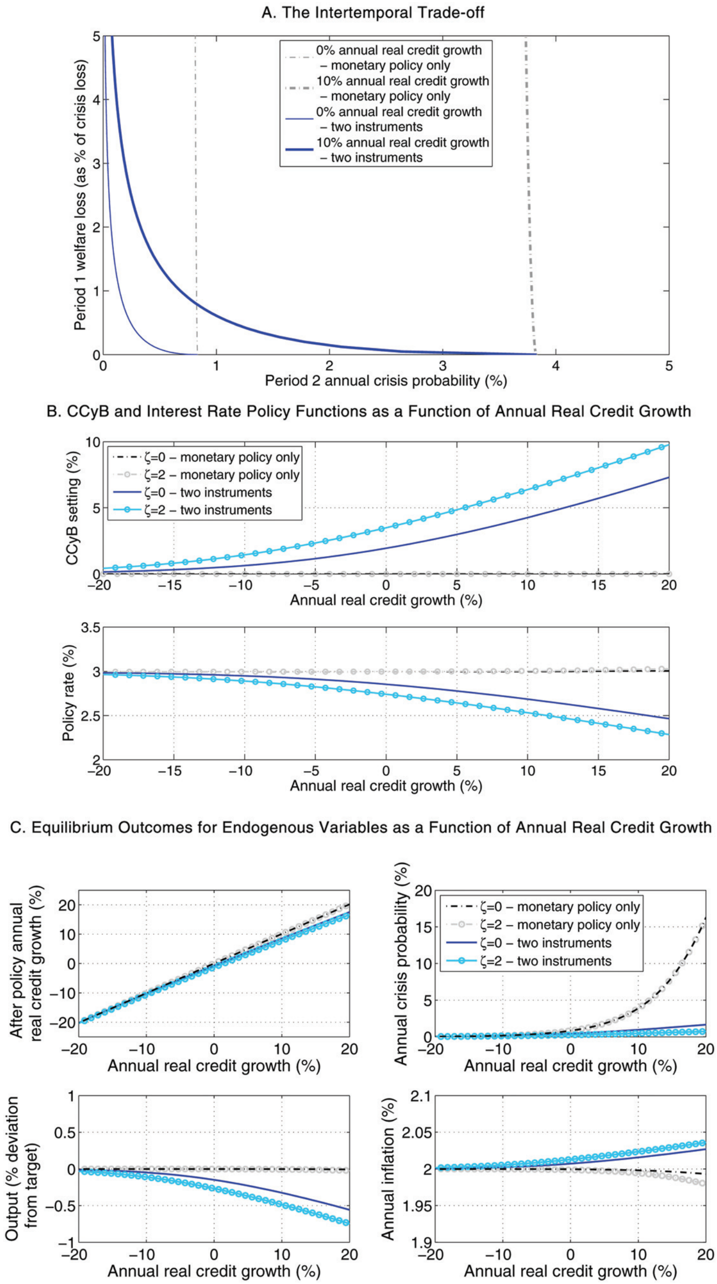
The grey dash-dotted lines in Figure 3A present this intertemporal trade-off. Each curve traces out the combination of inflation, output, and the crisis probability that minimizes the policymaker's loss function for different levels of ζ, the relative weight placed on maintaining financial stability 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 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 (11) is now augmented by the condition

$$\lambda y_1 \left(-\frac{\nu\psi}{\kappa}\right) = \left(\frac{\partial\gamma_1}{\partial k_1} + \frac{\partial\gamma_1}{\partial i_1}\left(\frac{\nu\psi}{\kappa\sigma} - \omega\psi\right)\right)\left(-\frac{\partial L}{\partial\gamma_1}\right). \tag{12}$$

Figure 3. Monetary and Financial Stability Trade-off with Monetary Policy and the CCyB



(continued)

Figure 3. (Continued)

Note: Panel A presents the trade-off facing a central bank 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 gray dash-dotted lines show the trade-off when the policymaker has access to monetary policy tools alone. These curves are obtained by varying ζ in Equation (11). The thin dash-dotted line shows the trade-off at 0 percent real credit growth; the thick dash-dotted line shows the trade-off at 10 percent per year growth in real credit for three years. The curves are drawn assuming that cost-push shocks, ξ_1^{π}, are zero. The blue solid lines in this panel plot the trade-off when both monetary policy and the CCyB are available tools. These are obtained by varying ζ in the solution to the full model derived in Appendix A. Panel B presents the optimal setting of the nominal interest rate and, where available, the CCyB, for varying levels of (pre-policy) annual real credit growth. Panel C presents the associated equilibrium outcomes for annual real credit growth, the annual probability of a crisis, the deviation of output from its target, and annual inflation. In both panels B and C, the lines and circles show the equilibrium oucomes, respectively, for the cases where $\zeta = 0$ and $\zeta = 2$. For each case, the dash-dotted gray lines show the outcomes when interest rates are the only tool, while the blue solid lines show outcomes with two tools.

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, summarized 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 on period 1 output of a tightening in the CCyB, offsetting somewhat the gains from running countercyclical macroprudential policy.

The blue solid lines in Figure 3A present the intertemporal trade-off facing a policymaker with access to both monetary policy and the CCyB (for figures in color, see the online version of the paper at http://www.ijcb.org). 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 stabilizing the crisis probability by matching the resilience of the banking system 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 stabilization. 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, reducing the level of potential output.

If there were no detrimental supply-side effects of using the CCyB—that is, if we were to 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 aggregate demand. 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 stabilization. Outside of this special case, there is always a trade-off between monetary and financial stability objectives for the policymaker to manage.

Figure 3B 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 for two 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 and helping to temper credit growth. 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. It is also clear that the response of monetary policy to credit growth in the absence of macroprudential policy is minimal under our calibration, in line with the results in Ajello et al. (2019).

To provide a sense of the quantitative variation in these instruments, when $\zeta = 0$, the CCyB response required to optimally stabilize the crisis probability in the face of annual real credit growth of 12.5 percent per year is around 5 percent. 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 percent is required for annual credit growth of only 5 percent per year.

Figure 3C illustrates how the trade-offs shown in Figure 3A arise. Without the CCyB, the costs of leaning against the wind—below target output and inflation—are too large, so as credit growth increases, the policymaker optimally accepts a high crisis probability (top right panel). With two instruments, the CCyB is used much more actively with higher credit growth. This is partly because interest rates are able to offset any pure demand effects of the CCyB, reducing the cost of using it. While there are still costs induced by the supply-side effects of the CCyB—below-target output and above-target inflation (bottom two panels)—these are balanced against the benefits of a much lower crisis probability. It takes only a relatively small reduction in real credit growth (top left panel) to lower the crisis probability, because the benefits accrue mainly from the resilience effect of the CCyB (captured by h_k).

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 stabilization 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

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	0.17	0.008	5.4	0.74	2.05	2.20	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

Note: 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 percent of losses incurred in the event of a financial crisis occurring in period 2. The results are reported for two alternative values of ζ, the relative weight placed on stabilizing the crisis probability in the loss function. For both sets of results, expected losses are shown as a percent of losses incurred in the event of a crisis assuming that $\zeta = 0$.

the sole disturbance to the economy, shown in rows (i)–(vi), and in a full stochastic simulation of the model using the shock variances reported in Table 1, shown in rows (vii)–(xii). For each case, we present one set of results for $\zeta = 0$, and one for $\zeta = 2$.[25]

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 volatility in output, inflation, and the nominal interest rate—this reflects the parsimonious structure of our model, in which 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 percent. This results in expected losses of 3.62 percent. 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 volatility 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 percent to 0.77 percent and 0.40 percent 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

[25]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 (11) and (12). 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.

of cost-push shocks in this case generates an irreducible trade-off between inflation and output stabilization 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 percent to 0.74 percent and 0.40 percent in the $\zeta = 0$ and $\zeta = 2$ cases, respectively, it now also slightly *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, as discussed further in Section 4.2. 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 2.2 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 percent.

We also find that the CCyB co-moves positively with lending growth in our full-shocks simulation but is close to uncorrelated with GDP. In particular, the correlation with lending growth is 0.60 for $\zeta = 0$, rising to 0.76 for the $\zeta = 2$ case where the policymaker weighs downside risks to GDP more heavily. By contrast, the correlation of the CCyB with output is 0.15 when $\zeta = 0$, and it falls to -0.06 for the $\zeta = 2$ case, reflecting the fact that more aggressive CCyB responses generate movements in GDP of opposite sign.[26]

4. When Are These Policies Complements vs. Substitutes?

As we have seen, under the benchmark calibration the CCyB and the interest rate are substitutes when tackling a credit boom: the policymaker finds it optimal to tighten the CCyB and to reduce interest

[26]Schmitt-Grohé and Uribe (2017) study the appropriate cyclicality of capital control instruments in an open-economy model with collateral constraints. In contrast to our findings, the Ramsey optimal policy in their model calls for capital control taxes to be *lowered* during booms and *increased* during recessions.

rates to cushion the resulting macroeconomic impact. But how general is this result? And how do the instruments jointly 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 summarize these cases in Table 5.

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, $\frac{\nu\psi}{\kappa}\frac{\kappa^2}{\kappa^2+\overline{\lambda}} > \sigma\omega\psi$, 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. In this case, macroprudential policy is also quite costly from a supply perspective so, at the margin, it makes sense to use monetary policy to support financial stability objectives.[27] As the impact of the CCyB on aggregate demand increases, or as the relative weight on inflation

[27]If a CCyB tightening were to *increase* aggregate demand (for example, due to expectational or confidence effects) 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.

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	+	+	$\frac{k^2}{k^2+\overline{\lambda}}\frac{v\psi}{k} > \sigma\omega\psi$	The impact of the CCyB on potential output sufficiently exceeds its impact on demand.
Instrument Substitutes	+	–	$\frac{v\psi}{k}\frac{k^2}{k^2+\overline{\lambda}} < \sigma\omega\psi$, $\frac{\frac{\partial\gamma_1}{\partial k_1}}{\frac{\partial\gamma_1}{\partial i_1}}\frac{\sigma}{\left(\sigma\omega\psi+\frac{k^2}{\lambda+k^2}\frac{v\psi}{k}\right)} > 1$	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	–	+	$\frac{\frac{\partial\gamma_1}{\partial k_1}}{\frac{\partial\gamma_1}{\partial i_1}}\frac{\sigma}{\left(\sigma\omega\psi+\frac{k^2}{\lambda+k^2}\frac{v\psi}{k}\right)} < 1$	Monetary policy has a comparative advantage for managing the crisis probability.

Note: The conditions in the table are derived in Appendix A. The parameter $\overline{\lambda}$, 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.

stabilization in the loss function falls, these policies switch to acting as instrument substitutes.

The result hinges on the relative magnitudes of demand and supply effects. Note that one factor influencing our result that the demand effects tend to dominate is our assumption that private-sector agents are not aware of the true crisis probability. As we show in Appendix A, when the private sector adjusts its expectations of future output rationally, then tightening the CCyB has a smaller negative impact on aggregate demand. This is because the reduction in demand from higher credit spreads is partly offset by higher (mean) expected output in period 2, arising from a lower crisis probability.

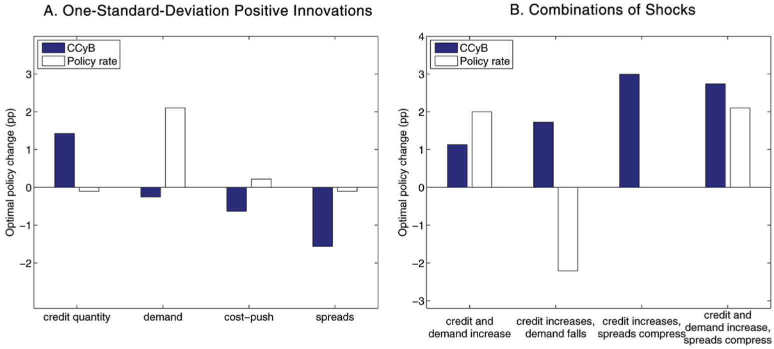
This expectations channel means that when credit growth and the crisis probability are high, it is more likely that the supply effects of the CCyB will dominate, and that the instruments will be complements and both tighten or loosen together in response to further credit shocks. However, under our benchmark calibration, the policies do not show instrument complementarity until the annual crisis probability reaches 3.25 percent. If crises are more costly, then the mitigating effects of the expectations channel are larger. If the costs are large enough, then tightening the CCyB may actually increase aggregate demand, which would imply instrument complementarity even if the potential supply effects of the CCyB were very small.

Turning to the issue of instrument assignment, the policymaker in our model sets monetary and macroprudential policies in a coordinated fashion to minimize an overall loss function comprising both monetary and financial stability objectives. She does not, therefore, have a built-in 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:

$$
\begin{aligned}
X &\equiv \frac{\frac{\partial \gamma_1}{\partial k_1}}{\frac{\partial \gamma_1}{\partial i_1}} \frac{(\lambda \frac{\partial y_1}{\partial i_1} + \kappa \frac{\partial \pi_1}{\partial i_1})}{(\lambda \frac{\partial y_1}{\partial k_1} + \kappa \frac{\partial \pi_1}{\partial k_1})} - 1 \\
&= \frac{\frac{\partial \gamma_1}{\partial k_1}}{\frac{\partial \gamma_1}{\partial i_1}} \frac{\sigma}{(\sigma \omega \psi + \frac{\kappa^2}{\lambda + \kappa^2} \frac{\nu \psi}{\kappa})} - 1, \qquad (13)
\end{aligned}
$$

Figure 4. Optimal Policy Responses to Shocks



Note: 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 standard deviation; 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.

where X is the ratio of the crisis probability and an average of the output and inflation elasticities with respect to the CCyB vis-à-vis those elasticities with respect to the interest rate (see also Appendix A). 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 $X > 0$, as in our benchmark calibration, 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. But if $X < 0$, the standard case is reversed and monetary policy becomes the instrument of choice for achieving financial stability goals, with the CCyB being used to achieve inflation and output stability.

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 4A presents optimal responses of the interest rate and CCyB to one-standard-deviation positive innovations to each of these shocks under the benchmark calibration of the model with $\zeta = 0$.

We start with the case of a positive aggregate demand shock, which raises output without having any impact on credit; this may be interpreted loosely as a government spending shock. The appropriate response is to tighten the interest rate significantly, leaving period 1 output little changed, as in the standard New Keynesian model. There is little role for the CCyB, 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 and lower output, the marginal cost of maintaining the CCyB increases.

The final part of Figure 4A shows the optimal response to a credit spread shock. This 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 could be interpreted as reflecting a credit crunch. It is optimal to loosen both instruments following this shock to cushion its impact on the economy, with the main response occurring via the CCyB. By acting in this way, the CCyB is balancing the need to offset the tightening in current credit conditions and support output with the need to maintain a sufficient level of resilience against the possibility of a crisis occurring next period. This policy prescription contrasts with the finding of Cúrdia and Woodford (2016). Their policymaker, with access only to a monetary policy tool, cuts interest rates enough to offset much of the 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, however, 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 or a positive shock to sentiment, for instance, it is likely that both credit growth and aggregate demand would increase rapidly. We can attempt to capture such mechanisms in our model by varying the correlation of the shocks. Figure 4B shows examples of the optimal response to combinations of one-standard-deviation shocks under the assumption that they are perfectly correlated with each other. The first case shows the policy response in 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. With aggregate demand and credit growth both 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 case shows the optimal response to the same two shocks under the assumption that they are negatively correlated. This could be thought of as capturing situations where financial stability risks increase but inflationary pressures and growth are subdued.[28] In this case, the instruments move in opposite directions: the CCyB tightens to offset the credit shock and the interest rate falls to offset the demand shock. Furthermore, the normal instrument substitutability leads to additional policy changes in the same direction.

[28]It is also related to the possibility discussed in Svensson (2017) that a negative output or unemployment gap in period 1 leads to a more costly crisis in period 2, because the crisis involves a fixed fall in output or a fixed rise in unemployment. We can capture the Svensson (2017) argument in our model by treating period 2 output in the crisis state as a direct function of its period 1 level: $y_{2,c} = c_0 + c_y y_1$. 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. 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.

The final two pairs of columns present cases that could be considered to represent credit supply shocks, with loosening terms and conditions on lending, which entail 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. The last case also includes a positive demand shock. 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 probability 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.

This analysis emphasizes that it is certainly possible that the CCyB and the nominal interest rate will need to be adjusted in opposite directions. Rather than signaling a policy conflict, 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.[29]

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 coordinated policy, whereby a single policymaker sets interest rates and the CCyB jointly to minimize an overall loss function comprising monetary and

[29] In the Bank of England working paper version of this paper, we document the shifting correlation between inflation pressures and financial vulnerabilities (i.e., the drivers of monetary and macroprudential responses, respectively) in the U.K. economy over the past 50 years. Overall, the correlation between these policy stance indicators has been highly unstable: there have been episodes where business and financial cycles have been divergent (the late 1970s and early 1980s), uncorrelated with one another (the run-up to the global financial crisis), and positively correlated (the late 1980s and the initial post-crisis period).

financial stability objectives, with 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 on interest rates. Third, we analyze the implications of introducing a market-based finance sector, which is not subject to the CCyB (Stein 2013).[30] Fourth, we consider the implications of the idea that low interest rates encourage excessive risk-taking by certain financial market participants, particularly those with explicit or implicit nominal return targets (Rajan 2006). Headline results from simulating the model under these various extensions are reported in Table 6 and are discussed below.

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 minimize 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 rather than by separate policymakers maximizing distinct objectives?

To explore this, we assign the monetary authority a loss function that only aims to stabilize 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 not to enter the monetary authority's calculus:

$$L_M = \frac{1}{2}(\pi_1^2 + \lambda y_1^2). \tag{14}$$

For the macroprudential authority, we assign a loss function that aims to minimize the crisis probability and which, in addition, penalizes volatility in output—recognizing that authorities with financial stability mandates typically seek to achieve an appropriate

[30]The CCyB typically only applies to banks in practice. For example, under the relevant European Union 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.

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) Effective Lower Bound on Interest Rates	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
$\zeta = 2$:							
(vi) Benchmark Results under CCyB Regime	0.13	0.006	5.2	0.40	0.13	1.74	2.48
(vii) Nash Policies	0.13	0.006	5.2	0.51	0.12	1.65	2.55
(viii) Effective Lower Bound on Interest Rates	0.14	0.046	5.4	1.19	0	1.15	5.79
(ix) Market-Based Finance	0.09	0.003	5.6	1.24	0.08	1.18	6.02
(x) Risk-taking Channel	0.15	0.003	6.1	0.51	0.12	1.82	2.94

(*continued*)

Table 6. (Continued)

Case	**SD(y_1)**	**SD(π_1)**	**SD(B_1)**	**Median(γ_1)**	**SD(i_1)**	**SD(k_1)**	***E*(*L*)**
Simulation Using All Shocks							
$\zeta = 0$:							
(xi) Benchmark Results under CCyB Regime	0.17	0.008	5.4	0.74	2.05	2.20	1.53
(xii) Nash Policies	0.15	0.008	5.4	0.92	2.05	2.32	1.57
(xiii) Effective Lower Bound on Interest Rates	0.73	0.778	5.7	1.32	1.01	2.29	112.14
(xiv) Market-Based Finance	0.15	0.007	5.7	1.56	2.04	2.00	2.51
(xv) Risk-taking Channel	0.17	0.011	7.5	0.83	1.99	2.30	2.39
$\zeta = 2$:							
(xvi) Benchmark Results under CCyB Regime	0.20	0.010	5.3	0.40	2.05	2.23	2.66
(xvii) Nash Policies	0.19	0.009	5.3	0.50	2.05	2.22	2.73
(xviii) Effective Lower Bound on Interest Rates	0.69	0.777	5.6	0.87	0.96	2.95	116.04
(xix) Market-Based Finance	0.17	0.007	5.7	1.31	2.04	1.83	6.30
(xx) Risk-taking Channel	0.23	0.034	8.5	0.48	1.97	2.64	5.55

Note: 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 percent of losses incurred in the event of a financial crisis occurring in period 2. The results are reported for two alternative values of ζ, the relative weight placed on stabilizing the crisis probability in the loss function. For both sets of results, expected losses are shown as a percent of losses incurred in the event of a crisis assuming that $\zeta = 0$. An effective lower bound of zero is imposed in all models for both instruments, but in the ELB simulation we also set $i^* = 0$ so that the nominal interest rate is constrained at zero even before any shocks are realized. For the market-based finance model, the share of market-based finance in total lending is calibrated as 25 percent ($b = 0.75$). In these rows B_1 refers to overall credit growth, given by the weighted average of that provided by banks and by market-based finance. For the risk-taking channel model, the interaction coefficient is calibrated as $\phi_{is} = -1000$.

balance between enhancing financial stability and near-term economic growth.[31] Again assuming no inflation losses from a crisis, this gives the following loss function:

$$L_F = \frac{1}{2}\lambda y_1^2 + \beta\gamma_1(1+\zeta)E_1[L_{2,c}] + \beta(1-\gamma_1)E_1[L_{2,nc}]. \qquad (15)$$

Each loss function is minimized subject to the same set of constraints as in the benchmark model, also taking the other policymaker's reaction function as given. The first-order condition for the monetary authority is

$$\sigma(\kappa\pi_1 + \lambda y_1) = 0. \qquad (16)$$

Compared with the jointly optimal case given by Equation (11), 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 spillover for financial 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

$$\lambda y_1(-\sigma\omega\psi) = \frac{\partial\gamma_1}{\partial k_1}\left(-\frac{\partial L_F}{\partial\gamma_1}\right). \qquad (17)$$

Relative to the jointly optimal case given by Equation (12), for a given setting of monetary policy, the CCyB is set at a lower level than under our benchmark calibration. This is because the macroprudential authority does not account for the fact that looser monetary policy can offset some of the demand costs of raising the CCyB.

How large are these distortions? Rows (ii), (vii), (xii), and (xvii) of Table 6 report summary statistics for the model's performance under the uncoordinated Nash regime. Overall, coordination 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), (vi), (xi), and (xvi) for convenience. The standard

[31] For example, the objective of the Bank of England's Financial Policy Committee is to protect and enhance the stability of the UK's financial system and, subject to that, to support the Government's economic objectives including those for growth and employment.

deviations of inflation, output, and credit growth are all virtually unchanged; the crisis probability increases somewhat, from 0.74 percent to 0.92 percent ($\zeta = 0$) and from 0.4 percent to 0.5 percent ($\zeta = 2$) 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 specialized expertise on committees, it seems likely that these could outweigh any losses resulting from less-than-fully coordinated policies.[32]

5.2 The Effective Lower Bound on Interest Rates

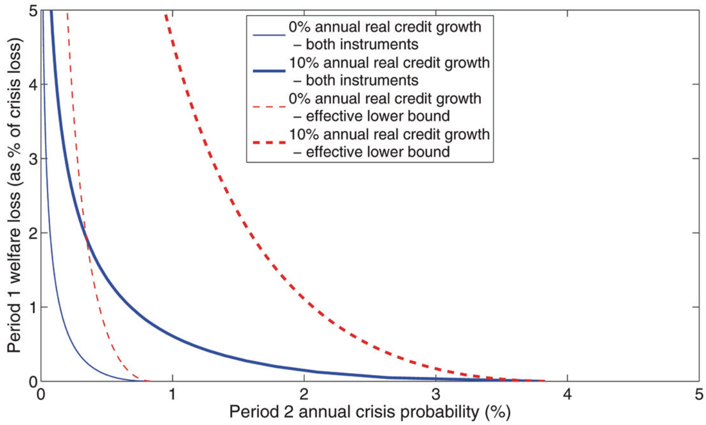
How could recognition of the effective lower bound (ELB) on nominal interest rates affect the trade-offs faced by the policymaker? Most obviously, in period 1, if interest rates are at the effective lower bound, monetary policy is unable to cushion the impact of increasing the CCyB, thus making the deployment of macroprudential policy more costly. This can be seen in Figure 5A. 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 start at their effective lower bound of zero (imposed by setting $i^* = 0$). It is evident that the trade-off facing the policymaker at the effective lower bound steepens, rotating out from the point on the horizontal axis where the CCyB is set at 0 percent.

Given the steeper trade-off, it is optimal to vary the CCyB less aggressively in the face of a credit shock, as illustrated by comparing the red dashed line in Figure 5B with the dark blue solid line. The appropriate CCyB setting corresponding to 12.5 percent credit growth falls from around 5 percent with unconstrained monetary policy to around 1.5 percent if monetary policy is constrained.

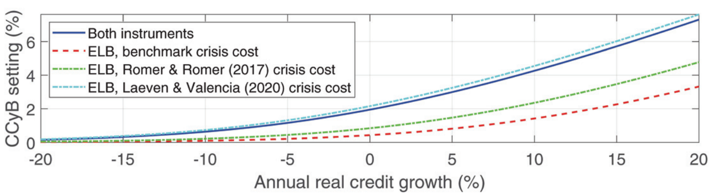
[32]We have also analyzed the case where the macroprudential authority acts as a Stackelberg leader, setting the CCyB first, with the monetary authority then setting interest rates given the chosen CCyB. This delivers similar results to the Nash equilibrium case. Details are available from the authors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

Figure 5. 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



Note: For an explanation of the upper panel, see the note to Figure 3A. 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 3B. The red, green, and cyan dashed lines show the optimal setting of the CCyB as a function of annual real credit growth when monetary policy is constrained at the effective lower bound. The red line uses a crisis cost of $y_{2,c} = 0.041$, or 4.1 percent of lost output per year for three years, our benchmark calibration of the cost of a crisis. The green line sets this 1.5 times higher to capture the effect of a binding ELB in period 2, based on the differential GDP effects from such crises reported by Romer and Romer (2017). The blue line sets it three times higher, roughly in line with the relative estimates of the cost of the 1997 Japanese financial crisis in Laeven and Valencia (2020).

This result is 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, with the standard deviation of the CCyB falling by one-half. Expected losses increase substantially as a result. The full simulation of the model, with the complete set of shocks, can be seen in the lower panel in Table 6. A comparison of rows (xiii) and (xi), and (xviii) and (xvi) 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 CCyB *increases* in this case. This is because, with monetary policy constrained, the CCyB is used as the primary macroeconomic stabilization tool. Expected losses in the full simulation are extremely large—bigger than the cost of a crisis itself. This largely results from realizations of negative shocks that are large enough that both instruments are floored at their lower bounds. In those realizations, because our model does not allow for any substitute monetary or macroprudential instruments, output and inflation losses are huge. Clearly, in reality, unconventional monetary policies could be used to help support macroeconomic objectives at the ELB.

This discussion does, however, highlight another potential interaction with the ELB in our model. If interest rates are still constrained when a financial crisis hits in period 2, the cost of that crisis is likely to be higher because expansionary monetary policy would then be restricted to unconventional policies. Knowing this, policymakers acting in period 1 may be more concerned about the risk of financial crises and therefore wish to respond more aggressively to that risk. We model this possibility by additionally assuming that a policymaker facing the ELB sets policy in period 1 under an assumption of higher than normal period 2 crisis costs.[33] Figure 5B shows

[33] An alternative way of capturing this possibility would be by increasing ζ in our loss function. Formally, we model the higher crisis cost under the ELB by assuming that the policymaker minimizes the loss function:

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

where $P(ELB)$ is the probability of still being at the ELB in period 2, and $E_1[L_{2,c,ELB}]$ and $E_1[L_{2,c,nELB}]$ are, respectively, the expected losses associated with a crisis at or away from the ELB. This loss function can be rewritten as

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

the results for two different calibrations of crisis costs at the ELB. The green line estimates the additional costs of crises at the ELB based on the differential GDP effects from such crises reported by Romer and Romer (2017), which yield a crisis cost which is one-and-a-half times greater than in the baseline. The light blue line takes the more extreme assumption that crises at the ELB will be as costly as the Japanese financial crisis of 1997, with the estimates of the cost of that crisis based roughly on Laeven and Valencia (2020) at three times the crisis cost assumption in the baseline. Overall, it is evident that even when accounting for this effect, the CCyB should probably be deployed somewhat less aggressively than when interest rates are unconstrained, especially if one considers that the high costs of the Japanese crisis probably reflected factors well beyond the ELB. It is also important to note that the setup and calibration here effectively assume that interest rates will be constrained in period 2 with certainty, even though there would always be some probability that the economy would move away from the ELB between periods 1 and 2. At the same time, allowing for higher period 2 crisis costs due to the ELB does clearly call for a more aggressive CCyB response than when only taking the period 1 effect of the ELB into account.

5.3 "Getting in All the Cracks": Introducing a Market-Based Finance 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 companies, investment funds, hedge funds, and other non-bank financial sector entities. This allows us to analyze leakages from the application of the CCyB, in which the banking system is disintermediated by non-bank financial institutions that are able to hold debt liabilities of the private non-financial sector more cheaply than banks as a result of not being subject to the CCyB. This introduces a limit to the effectiveness of the CCyB

where $\overline{\zeta} = \zeta + (1+\zeta)P(ELB)\frac{(E_1[L_{2,c,ELB}]-E_1[L_{2,c,nELB}])}{E_1[L_{2,c,nELB}]}$. This shows that a higher crisis cost under the ELB can be captured by a higher weight $\overline{\zeta}$ on avoiding crises, with the extra weight equal to the probability of still being at the ELB in period 2, $P(ELB)$, multiplied by the percentage increase in expected loss from being at the ELB when a crisis hits.

in reducing the crisis probability, as it cannot lower the probability of a crisis emanating from the market-based finance sector.

We introduce market-based finance by letting the probability of a crisis be given by

$$\gamma_1 = b\gamma_1^B + (1-b)\gamma_1^M, \tag{18}$$

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 percent of total U.K. financial system assets (Bank of England 2017).

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

$$B_1^B = \phi_0^B + \phi_i i_1 + \phi_s^B s_1 + \xi_1^B \tag{19}$$

$$B_1^M = \phi_0^M + \phi_i i_1 + \phi_s^M s_1 + \xi_1^M. \tag{20}$$

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 the market-based finance sector. The interest rate 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, despite the latter being subject to capital requirements.

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 point; that is, we set $b\phi_s^M = -0.33(1-b)\phi_s^B$.[34]

[34] 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.

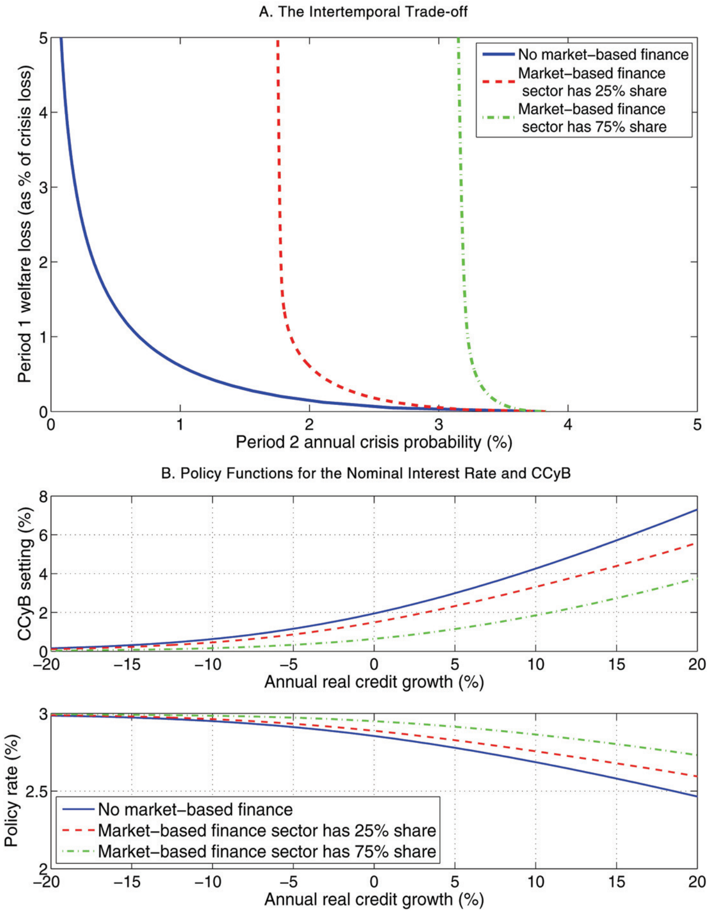
This is based on the Aiyar, Calomiris, and Wieladek (2014) study of the leakage to U.K.-resident foreign branches when supervisory capital requirements are increased for domestically incorporated banks. The authors find this leakage to be substantial: about one-third of the reduction in lending by domestic banks following an increase in required capital is offset by an increase in lending by foreign branches.[35]

Figure 6A 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 percent of lending; the green dash-dotted line shows the equivalent trade-off when this sector accounts for 75 percent of lending. In both cases the trade-off worsens relative to the benchmark model (shown by the blue solid line) because any positive setting of the CCyB generates smaller financial stability benefits. It is striking that, at crisis probabilities of just under 2 percent per year for the 25 percent market-based finance sector case and at just over 3 percent per year for the 75 percent 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 6B illustrates how optimal policy settings change in this case, as a function of credit growth. 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

[35] Cizel et al. (2019) find evidence of substitution effects from bank towards non-bank 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 6. Monetary and Financial Stability Policy with a Market-Based Finance Sector of Varying Magnitudes



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

deploying such tools alongside bank-based macroprudential policies. At the same time, 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 for the case where the market-based finance sector has a share of 25 percent in total credit. Relative to the benchmark case, the volatility of total credit growth increases, while the volatilities 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 finance sector. It is therefore optimal to use it less: the volatility of the CCyB falls from 2.20 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

Finally, we extend the model to capture the idea that, when policy rates are low and capital requirements are high, banks might be incentivized to take on excessive risk to meet return on equity targets.[36] We do so by augmenting Equation (5) to introduce a nonlinear interaction term between the interest rate and the CCyB. This is consistent with Dell'Ariccia, Laeven, and Suarez (2017), who find that the risk-taking propensity of U.S. banks rises as real policy rates fall but that the correlation is less pronounced when banking system capital is weak.

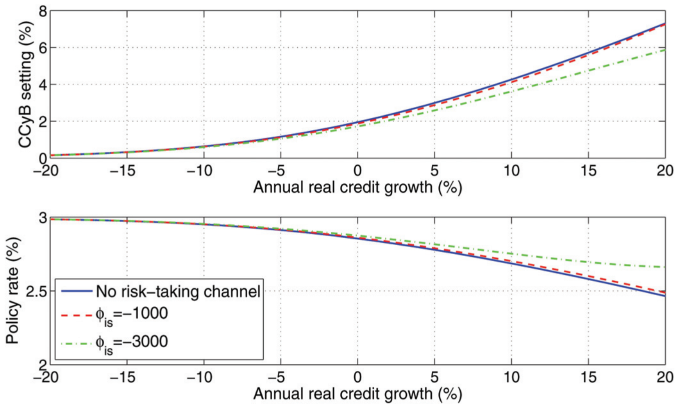
In this extension, B_1 is determined by

$$B_1 = \phi_0 + \phi_i i_1 + \phi_s s_1 + \phi_{i,s} i_1 s_1 + \xi_1^B, \tag{21}$$

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.

[36] Credit growth would also be highly interest sensitive in a setting where debt capacity is a function of the value of borrowers' collateral which is, in turn, a function of interest rates, as in Kiyotaki and Moore (1997).

Figure 7. Optimal Policy Responses to a Credit Boom: Benchmark Model vs. Risk-taking Channel Extension



Note: 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 analyzed 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 $\phi_{i,}s = -3000$.

The consequences for optimal policy are illustrated in Figure 7. The red dashed lines set an interaction coefficient of $\phi_{i,s} = -1000$, which implies that with interest rates 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 an 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.

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

6. Conclusion

We develop a simple, calibrated model to explore how monetary and macroprudential policies affect the economy and interact with each other in a setup that ascribes a clear role for the resilience-enhancing benefits of the CCyB. 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 bank toolkits including this policy lever.

The CCyB and monetary policy are substitutes in our benchmark model: faced with a credit boom, it is appropriate to tighten the CCyB and to cushion its macroeconomic impact by cutting interest rates. Under our preferred model specification, the policymaker chooses to vary the CCyB quite aggressively. For instance, a CCyB of 5 percent is required to stabilize the crisis probability when credit growth persistently reaches around 12.5 percent per year. And, in a full stochastic simulation of the model, the standard deviation of the CCyB is around 2.2 percentage points. But despite its powerful role, we find that the CCyB should be used somewhat less aggressively when monetary policy is constrained at the effective lower bound, when there is a large market-based finance sector outside the reach of the CCyB, or when the risk-taking channel of monetary policy is strong.

A key strength of our parsimonious modeling framework is that it can also provide a flexible structure to explore other key issues relating to macroprudential policy strategy and design. For example, as discussed by Shafik (2016), the model may be extended to highlight the benefits of international reciprocity in CCyB policymaking. More generally, future work could consider the role of borrower-based macroprudential instruments, macroprudential policies for the nonbank financial sector, or wider international spillovers. As such, the model may help to provide the foundations of a flexible framework that could be used to explore a range of practical policy questions which confront macroprudential regimes.

Appendix A. Solving the Model

A.1 Minimizing the Loss Function

The period 1 policymaker chooses period 1 settings of the CCyB and interest rates to minimize the loss function,

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

subject to the Phillips curve,

$$\pi_1 = \kappa y_1 + E_1^{ps}\pi_2 + \nu s_1 + \xi_1^{\pi}, \quad \text{(A.2)}$$

the IS curve,

$$y_1 = E_1^{ps}y_2 - \sigma(i_1 - E_1^{ps}\pi_2 + \omega s_1) + \xi_1^{y}, \quad \text{(A.3)}$$

the equation determining credit growth,

$$B_1 = \phi_0 + \phi_i i_1 + \phi_s s_1 + \xi_1^{B}, \quad \text{(A.4)}$$

the equation for credit spreads,

$$s_1 = \psi k_1 + \xi_1^{s}, \quad \text{(A.5)}$$

and the crisis probability equation,

$$\gamma_1 = \frac{\exp(h_0 + h_B B_1 + h_k k_1)}{1 + \exp(h_0 + h_B B_1 + h_k k_1)}. \quad \text{(A.6)}$$

So the policymaker's problem is

$$min_{i_1,k_1} L = \frac{1}{2}(\pi_1^2 + \lambda y_1^2) + \beta\gamma_1(1+\zeta)E_1[L_{2,c}] + \beta(1-\gamma_1)E_1[L_{2,nc}] \quad \text{(A.7)}$$

subject to (A.2)–(A.6).

We then substitute (A.2) in place of π_1 in (A.7), (A.3) in place of y_1, and (A.5) 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.[37] Differentiating with respect to i_1 and k_1 gives the two first-order necessary conditions which hold at the minimized value of L:[38]

$$\frac{\partial L}{\partial i_1} = -\sigma(\kappa\pi_1 + \lambda y_1) + \frac{\partial \gamma_1}{\partial i_1}\beta((1+\zeta)E_1[L_{2,c}] - E_1[L_{2,nc}]) = 0 \tag{A.8}$$

$$\frac{\partial L}{\partial k_1} = -\sigma\omega\psi(\kappa\pi_1 + \lambda y_1) + \nu\psi\pi_1 + \frac{\partial \gamma_1}{\partial k_1}\beta((1+\zeta)E_1[L_{2,c}] - E_1[L_{2,nc}]) = 0. \tag{A.9}$$

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.[39] For $\zeta > -1$, a sufficient condition for (A.8) and (A.9) to define a global minimum is as follows:

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 minimized, 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

[37]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.

[38]In the monetary-policy-only case, (A.8) is the sole first-order condition.

[39]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 $\zeta = -1 + \frac{E_1[L_{2,nc}]}{E_1[L_{2,c}]}$.

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 conditions 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 had become so misaligned that with inflation at target and output equal to potential, the crisis probability was greater than 50 percent per year. While theoretically possible, such an extreme misalignment seems unrealistic, particularly in light of our empirical model estimate that the U.K. crisis probability peaked at only around 12 percent in the 2000s. We therefore opt to ignore the extreme regions of the parameter space, or shock realizations, where Condition 1 does not hold.[40]

To gain some intuition into the first-order conditions, we can substitute into the crisis probability (A.6), the equation determining credit growth (A.4), as well as the Phillips curve (A.2), IS curve (A.3), and the equation for spreads (A.5), to give an equation in terms of the two policy instruments. Differentiating this using the chain rule gives the two marginal crisis risk equations:

$$\begin{aligned}\left(\frac{\partial\gamma_1}{\partial i_1}\right)_{k_1} &= \left(\frac{\partial\gamma_1}{\partial B_1}\right)_{k_1,i_1}\left(\frac{\partial B_1}{\partial i_1}\right)_{k_1}\\ &= \left(\frac{\exp(h_0+h_BB_1+h_kk_1)}{(1+\exp(h_0+h_BB_1+h_kk_1))^2}h_B\right)\left(\frac{\partial B_1}{\partial i_1}\right)_{k_1}\\ &= \frac{\exp(h_0+h_BB_1+h_kk_1)}{(1+\exp(h_0+h_BB_1+h_kk_1))^2}h_B\phi_i \qquad \text{(A.10)}\end{aligned}$$

$$\begin{aligned}\left(\frac{\partial\gamma_1}{\partial k_1}\right)_{i_1} &= \left(\frac{\partial\gamma_1}{\partial B_1}\right)_{k_1,i_1}\left(\frac{\partial B_1}{\partial k_1}\right)_{i_1} + \left(\frac{\partial\gamma_1}{\partial k_1}\right)_{B_1,i_1}\\ &= \left(\frac{\exp(h_0+h_BB_1+h_kk_1)}{(1+\exp(h_0+h_BB_1+h_kk_1))^2}h_B\right)\left(\frac{\partial B_1}{\partial k_1}\right)_{i_1}\\ &\quad + \left(\frac{\exp(h_0+h_BB_1+h_kk_1)}{(1+\exp(h_0+h_BB_1+h_kk_1))^2}h_k\right)\end{aligned}$$

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

$$= \frac{\exp(h_0 + h_B B_1 + h_k k_1)}{(1 + \exp(h_0 + h_B B_1 + h_k k_1))^2}(h_B(\psi\phi_s) + h_k), \tag{A.11}$$

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

$$\frac{\frac{\partial \gamma_1}{\partial k_1}}{\frac{\partial \gamma_1}{\partial i_1}} = \frac{h_B \psi \phi_s + h_k}{h_B \phi_i}. \tag{A.12}$$

Next, multiplying through (A.8) by $-\frac{\frac{\partial \gamma_1}{\partial k_1}}{\frac{\partial \gamma_1}{\partial i_1}}$, and adding to (A.9), gives

$$\left(\frac{\frac{\partial \gamma_1}{\partial k_1}}{\frac{\partial \gamma_1}{\partial i_1}}\sigma - \sigma\omega\psi\right)(\kappa\pi_1 + \lambda y_1) + \nu\psi\pi_1 = 0. \tag{A.13}$$

This can be expressed as

$$\overline{\lambda} y_1 + \kappa\pi_1 = 0, \tag{A.14}$$

where

$$\overline{\lambda} \equiv \frac{\chi\sigma\omega\psi}{\frac{\nu\psi}{\kappa} + \chi\sigma\omega\psi}\lambda \tag{A.15}$$

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 supply.

$$\chi \equiv \frac{h_B \phi_s \psi + h_k}{h_B \phi_i \omega\psi} - 1 = \frac{\frac{\partial \gamma_1}{\partial k_1}\frac{\partial y_1}{\partial i_1}}{\frac{\partial \gamma_1}{\partial i_1}\frac{\partial y_1}{\partial k_1}} - 1 \tag{A.16}$$

In addition, (A.8) can be multiplied by $(\frac{\nu\psi}{\kappa\sigma} - \omega\psi)$ and added to (A.9) to give an intertemporal optimality condition trading off changes in the crisis probability with output/inflation losses in period 1:

$$\lambda y_1 \left(-\frac{\nu\psi}{\kappa}\right) = \left(\frac{\partial \gamma_1}{\partial k_1} + \frac{\partial \gamma_1}{\partial i_1}\left(\frac{\nu\psi}{\kappa\sigma} - \omega\psi\right)\right)\left(-\frac{\partial L}{\partial \gamma_1}\right), \tag{A.17}$$

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.

$$\frac{\partial L}{\partial \gamma_1} = \beta((1+\zeta)E_1[L_{2,c}] - E_1[L_{2,nc}]) \tag{A.18}$$

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

$$\pi_1 \frac{\partial \pi_1}{\partial k_1} = \left(\frac{\partial \gamma_1}{\partial k_1} - \frac{\partial \gamma_1}{\partial i_1} \frac{\frac{\partial y_1}{\partial k_1}}{\frac{\partial y_1}{\partial i_1}} \right) \left(-\frac{\partial L}{\partial \gamma_1} \right). \tag{A.19}$$

The left-hand side 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 right-hand side 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 (A.2) in place of π_1 in (A.14) and (A.5) in place of s_1 gives

$$\kappa^2 y_1 + \kappa E_1^{ps} \pi_2 + \kappa \nu \psi k_1 + \kappa \nu \xi_1^s + \kappa \xi_1^\pi + \overline{\lambda} y_1 = 0. \tag{A.20}$$

This can be rearranged to give

$$y_1 = -\frac{\kappa}{\kappa^2 + \overline{\lambda}} (E_1^{ps} \pi_2 + \nu \psi k_1 + \nu \xi_1^s + \xi_1^\pi). \tag{A.21}$$

Substituting into this (A.3) in place of y_1 and (A.5) 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:

$$\begin{aligned} i_1 = & \frac{\kappa}{\sigma(\kappa^2 + \overline{\lambda})}(E_1^{ps}\pi_2 + \nu\psi k_1 + \nu\xi_1^s + \xi_1^\pi) \\ & + \frac{E_1^{ps}y_2 + \xi_1^y}{\sigma} - \omega\psi k_1 - \omega\xi_1^s + E_1^{ps}\pi_2. \end{aligned} \tag{A.22}$$

The instruments are instrument substitutes if and only if, at the optimal settings of each instrument, $\frac{di}{dk} < 0$. Differentiating (A.22) gives

$$\frac{di_1}{dk_1} = \frac{\kappa}{\sigma(\kappa^2 + \overline{\lambda})}\nu\psi - \omega\psi. \tag{A.23}$$

This is less than zero if and only if

$$\frac{\kappa}{\kappa^2 + \overline{\lambda}}\nu\psi < \sigma\omega\psi. \tag{A.24}$$

Otherwise there is instrument complementarity.

To find which direction the instruments move in response to a credit shock, note that (A.22) 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 (A.21) in place of y_1 in (A.17), then rearrange and substitute out for $\overline{\lambda}$ using (A.15) to give

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

$$= \frac{(\kappa^2+\lambda)\chi\sigma\omega\psi + \kappa^2\frac{\nu\psi}{\kappa}}{\lambda\sigma\nu^2\psi^2}\frac{\partial\gamma_1}{\partial i_1}\left(-\frac{\partial L}{\partial\gamma_1}\right) - \frac{E_1^{ps}\pi_2}{\nu\psi} - \frac{\xi_1^{\pi}}{\nu\psi} - \frac{\xi_1^s}{\psi}. \tag{A.25}$$

And substituting in (A.18) for $\frac{\partial L}{\partial\gamma_1}$ gives

$$\begin{aligned} k_1 = {} & \frac{(\kappa^2+\lambda)\chi\sigma\omega\psi + \kappa^2\frac{\nu\psi}{\kappa}}{\lambda\sigma\nu^2\psi^2}\frac{\partial\gamma_1}{\partial i_1}(-\beta((1+\zeta)E_1[L_{2,c}] \\ & - E_1[L_{2,nc}])) - \frac{E_1^{ps}\pi_2}{\nu\psi} - \frac{\xi_1^{\pi}}{\nu\psi} - \frac{\xi_1^s}{\psi}. \end{aligned} \tag{A.26}$$

Differentiating this with respect to ξ_1^B gives

$$\begin{aligned} \frac{dk_1}{d\xi_1^B} = {} & \frac{(\kappa^2+\lambda)\chi\sigma\omega\psi + \kappa^2\frac{\nu\psi}{\kappa}}{\lambda\sigma\nu^2\psi^2}(-\beta((1+\zeta)E_1[L_{2,c}] \\ & - E_1[L_{2,nc}]))\frac{d\frac{\partial\gamma_1}{\partial i_1}}{d\xi_1^B}. \end{aligned} \tag{A.27}$$

From (A.10),

$$\frac{\partial\gamma_1}{\partial i_1} = \frac{\exp(h_0 + h_B B_1 + h_k k_1)}{(1+\exp(h_0 + h_B B_1 + h_k k_1))^2} h_B\phi_i. \tag{A.28}$$

Using the chain rule,

$$\begin{aligned} \frac{d\frac{\partial\gamma_1}{\partial i_1}}{d\xi_1^B} = {} & \left(\frac{\partial\frac{\partial\gamma_1}{\partial i_1}}{\partial B_1}\right)_{k_1}\left(\frac{\partial B_1}{\partial\xi_1^B}\right)_{i_1,k_1} + \left(\left(\frac{\partial\frac{\partial\gamma_1}{\partial i_1}}{\partial B_1}\right)_{k_1}\left(\left(\frac{\partial B_1}{\partial i_1}\right)_{k_1}\frac{di_1}{dk_1}\right.\right. \\ & \left.\left. + \left(\frac{\partial B_1}{\partial k_1}\right)_{i_1}\right) + \left(\frac{\partial\frac{\partial\gamma_1}{\partial i_1}}{\partial k_1}\right)_{B_1}\right)\frac{dk_1}{d\xi_1^B} \\ = {} & \left(\frac{\partial\frac{\partial\gamma_1}{\partial i_1}}{\partial B_1}\right)_{k_1} + \left(\left(\frac{\partial\frac{\partial\gamma_1}{\partial i_1}}{\partial B_1}\right)_{k_1}\left(\phi_i\frac{di_1}{dk_1} + \phi_s\psi\right)\right. \\ & \left. + \left(\frac{\partial\frac{\partial\gamma_1}{\partial i_1}}{\partial k_1}\right)_{B_1}\right)\frac{dk_1}{d\xi_1^B} \end{aligned}$$

$$= \frac{\exp(h_0 + h_B B_1 + h_k k_1) - \exp(h_0 + h_B B_1 + h_k k_1)^2}{(1 + \exp(h_0 + h_B B_1 + h_k k_1))^3}$$
$$h_B \phi_i \left(h_B + \left(h_B \left(\phi_i \frac{di_1}{dk_1} + \phi_s \psi \right) + h_k \right) \frac{dk_1}{d\xi_1^B} \right). \qquad \text{(A.29)}$$

If we let $\alpha_1 \equiv \frac{(\kappa^2+\lambda)\chi\sigma\omega\psi+\kappa^2\frac{\nu\psi}{\kappa}}{\lambda\sigma\nu^2\psi^2}$, $\alpha_2 \equiv -\beta((1+\zeta)E_1[L_{2,c}] - E_1[L_{2,nc}])$,
$\alpha_3 \equiv \frac{(1-\exp(h_0+h_B B_1+h_k k_1))\exp(h_0+h_B B_1+h_k k_1)}{(1+\exp(h_0+h_B B_1+h_k k_1))^3}$, 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 (A.27) as

$$\frac{dk_1}{d\xi_1^B} = \alpha_1\alpha_2\alpha_3\left(h_B^2\phi_i + \alpha_4\frac{dk_1}{d\xi_1^B}\right)$$
$$= \frac{h_B^2\phi_i\alpha_1\alpha_2\alpha_3}{1-\alpha_1\alpha_2\alpha_3\alpha_4}. \qquad \text{(A.30)}$$

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 minimum.

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.

$$\alpha_1 - \alpha_4 = \frac{(\kappa^2+\lambda)\chi\sigma\omega\psi+\kappa^2\frac{\nu\psi}{\kappa}}{\lambda\sigma\nu^2\psi^2}$$
$$- \left(h_B^2\phi_i\left(\phi_i\frac{di_1}{dk_1}+\phi_s\psi\right)+h_B h_k\phi_i\right)$$

$$\begin{aligned}
\iff \frac{\lambda\nu^2\psi^2}{\kappa^2+\lambda}\alpha_1 - \frac{\alpha_4}{(h_B\phi_i)^2} &= \chi\omega\psi + \frac{\kappa^2}{\kappa^2+\lambda}\frac{\nu\psi}{\kappa} \\
&\quad - \left(\frac{di_1}{dk_1} + \frac{h_B\phi_s\psi + h_k}{h_B\phi_i}\right) \\
&= \frac{h_B\phi_s\psi + h_k}{h_B\phi_i} - \omega\psi + \frac{\kappa^2}{\kappa^2+\lambda}\frac{\nu\psi}{\kappa\sigma} \\
&\quad - \left(\frac{di_1}{dk_1} + \frac{h_B\phi_s\psi + h_k}{h_B\phi_i}\right) \\
&= \frac{\nu\psi}{\kappa\sigma}\left(\frac{\kappa^2}{\kappa^2+\lambda} - \frac{\kappa^2}{\kappa^2+\overline{\lambda}}\right) \\
&= \frac{\nu\psi\kappa}{\sigma(\kappa^2+\lambda)}\left(\frac{\overline{\lambda}-\lambda}{\kappa^2+\overline{\lambda}}\right) \\
&= \frac{\nu\psi\kappa}{\sigma(\kappa^2+\lambda)}\left(\frac{\frac{\chi\sigma\omega\psi}{\frac{\nu\psi}{\kappa}+\chi\sigma\omega\psi}\lambda - \lambda}{\kappa^2 + \frac{\chi\sigma\omega\psi}{\frac{\nu\psi}{\kappa}+\chi\sigma\omega\psi}\lambda}\right) \\
&= \frac{\nu\psi\kappa}{\sigma(\kappa^2+\lambda)}\left(\frac{-\lambda\frac{\nu\psi}{\kappa}}{(\kappa^2+\lambda)\chi\sigma\omega\psi + \kappa^2\frac{\nu\psi}{\kappa}}\right) \\
&= \frac{-1}{\sigma^2(\kappa^2+\lambda)\alpha_1} \qquad \text{(A.31)}
\end{aligned}$$

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,

$$\begin{aligned}
&\frac{(\kappa^2+\lambda)\chi\sigma\omega\psi + \kappa^2\frac{\nu\psi}{\kappa}}{\lambda\sigma\nu^2\psi^2} > 0 \\
\iff &\frac{\frac{\partial\gamma_1}{\partial k_1}}{\frac{\partial\gamma_1}{\partial i_1}} > \left(\sigma\omega\psi - \nu\psi\frac{\kappa}{\kappa^2+\lambda}\right)\sigma^{-1} \\
\iff &\frac{\frac{\partial\gamma_1}{\partial k_1}}{\frac{\partial\gamma_1}{\partial i_1}}\frac{\sigma}{(\sigma\omega\psi + \frac{\kappa^2}{\lambda+\kappa^2}\frac{\nu\psi}{\kappa})} > 1. \qquad \text{(A.32)}
\end{aligned}$$

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:

$$\begin{aligned} X &\equiv \frac{\frac{\partial \gamma_1}{\partial k_1}}{\frac{\partial \gamma_1}{\partial i_1}} \frac{(\lambda \frac{\partial y_1}{\partial i_1} + \kappa \frac{\partial \pi_1}{\partial i_1})}{(\lambda \frac{\partial y_1}{\partial k_1} + \kappa \frac{\partial \pi_1}{\partial k_1})} - 1 \\ &= \frac{\frac{\partial \gamma_1}{\partial k_1}}{\frac{\partial \gamma_1}{\partial i_1}} \frac{\sigma}{(\sigma \omega \psi + \frac{\kappa^2}{\lambda + \kappa^2} \frac{\nu \psi}{\kappa})} - 1. \end{aligned} \tag{A.33}$$

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

A.3 Private-Sector Expectations

In the benchmark model presented in the paper, we assume that private-sector agents' expectations of period 2 outcomes are exogenous, implying that they do not take into account the impact of extra borrowing on the probability of a future financial crisis. When we calibrate the model, we also assume for simplicity that this exogenous probability is zero: agents do not perceive any possibility of a future financial crisis. While these assumptions have some empirical support, they may not hold at all times.

In this subsection we explore how our results change when we relax each assumption. We show that the main findings are relatively little changed even under different assumptions about private-sector expectations.

A.3.1 Different Exogenous Private-Sector Expectations

We first examine the effect of varying private-sector expectations while retaining the model assumption that these expectations are exogenous. Our calibration of period 2 outturns is that inflation remains at target whether or not there is a crisis, which implies that private-sector inflation expectations, $E_1^{ps}\pi_2$, have no effect on any outcomes. Given that calibration, we focus on varying private-sector output expectations, $E_1^{ps}y_2$. For alternative calibrations of period 2 inflation outturns, the effect of varying private-sector inflation expectations is somewhat more complex, as doing so also influences the inflation-output trade-off facing the policymaker.

To explore the effect of varying private-sector output expectations, it is instructive to generalize the equation determining credit growth by replacing (A.4) with

$$B_1 = \phi_0 + \phi_i i_1 + \phi_s s_1 + \phi_y E_1^{ps} y_2 + \xi_1^B, \tag{A.34}$$

where ϕ_y represents the elasticity of credit growth to future output expectations. The additional term allows for the fact that changes in expectations of future output may also influence the demand for credit. When $E_1^{ps}y_2 = 0$, as in the model presented in the main text, then the equation reduces to the equation for credit growth given by (A.4). Note that the if we parameterize the elasticities in (A.34) such that $\phi_i = -\phi_y\sigma$ and $\phi_s = -\phi_y\sigma\omega$, and assuming that $E_1^{ps}\pi_2 = 0$, then (A.34) would reduce to $B_1 = \phi_0 + \phi_y y_1 + \xi_1^B$. Credit growth would depend only on current output and an exogenous shock. Our equation nests this model but allows for the possibility that different settings for the CCyB and interest rates can alter the credit intensity of a given amount of output.

We can show the effect of varying $E_1^{ps}y_2$ very similarly to the effect of varying ξ_1^B in the previous subsection. Differentiating (A.26) with respect to $E_1^{ps}y_2$ gives

$$\begin{aligned}\frac{dk_1}{dE_1^{ps}y_2} = {} & \frac{(\kappa^2+\lambda)\chi\sigma\omega\psi + \kappa^2\frac{\nu\psi}{\kappa}}{\lambda\sigma\nu^2\psi^2}(-\beta((1+\zeta)E_1[L_{2,c}] \\ & - E_1[L_{2,nc}]))\frac{d\frac{\partial\gamma_1}{\partial i_1}}{dE_1^{ps}y_2}. \end{aligned} \tag{A.35}$$

Again, differentiating (A.10) using the chain rule gives

$$\begin{aligned}\frac{d\frac{\partial\gamma_1}{\partial i_1}}{dE_1^{ps}y_2} = {} & \left(\frac{\partial\frac{\partial\gamma_1}{\partial i_1}}{\partial B_1}\right)_{k_1}\left(\left(\frac{\partial B_1}{\partial E_1^{ps}y_2}\right)_{i_1,k_1}\right. \\ & \left. + \left(\frac{\partial B_1}{\partial i_1}\right)_{E_1^{ps}y_2,k_1}\left(\frac{\partial i_1}{\partial E_1^{ps}y_2}\right)_{k_1}\right)\end{aligned}$$

$$
\begin{aligned}
&+\left(\left(\frac{\partial\frac{\partial\gamma_1}{\partial i_1}}{\partial B_1}\right)_{k_1}\left(\left(\frac{\partial B_1}{\partial i_1}\right)_{k_1}\frac{di_1}{dk_1}+\left(\frac{\partial B_1}{\partial k_1}\right)_{i_1}\right)\right.\\
&\left.+\left(\frac{\partial\frac{\partial\gamma_1}{\partial i_1}}{\partial k_1}\right)_{B_1}\right)\frac{dk_1}{dE_1^{ps}y_2}\\
=&\left(\frac{\partial\frac{\partial\gamma_1}{\partial i_1}}{\partial B_1}\right)_{k_1}\left(\phi_y+\frac{\phi_i}{\sigma}\right)\\
&+\left(\left(\frac{\partial\frac{\partial\gamma_1}{\partial i_1}}{\partial B_1}\right)_{k_1}\left(\phi_i\frac{di_1}{dk_1}+\phi_s\psi\right)+\left(\frac{\partial\frac{\partial\gamma_1}{\partial i_1}}{\partial k_1}\right)_{B_1}\right)\frac{dk_1}{dE_1^{ps}y_2},
\end{aligned}
\tag{A.36}
$$

where we use (A.22) to calculate $\left(\frac{\partial i_1}{\partial E_1^{ps}y_2}\right)_{k_1}=\frac{1}{\sigma}$. This derivative implies that for a given setting of the CCyB, the partial response of monetary policy is to completely offset the effects of changes in expectations on current output. If agents expect a higher crisis probability, and therefore lower expected output, for example, the policymaker is able to lower interest rates such that the increased pessimism does not translate into any changes in current output. The total response, however, also depends on the optimal response of the CCyB.

By comparing (A.35) and (A.36) with the equivalent derivatives for credit shocks, (A.27) and (A.29), we can see that

$$
\frac{dk_1}{dE_1^{ps}y_2}=\left(\phi_y+\frac{\phi_i}{\sigma}\right)\frac{dk_1}{d\xi_1^B}. \tag{A.37}
$$

This equation shows that the optimal response of the CCyB to changes in future output expectations is very similar to the response to a credit shock. This arises because in equilibrium, changes in the private-sector's expectations for future output only affect outcomes to the extent that they affect credit growth. In the special case discussed above where credit growth depends only on output, $\phi_i=-\phi_y\sigma$, which implies that $\frac{dk_1}{dE_1^{ps}y_2}=0$. The only effect of changes in expectations about the crisis probability and period 2 output is that the optimal setting of monetary policy is adjusted to entirely offset its effect on all other variables.

More generally, when the relative elasticities of credit growth and output to interest rates differ from the relative elasticities to future output expectations, then any attempt by monetary policy to perfectly offset changes in optimism or pessimism about future output or crises would lead to a change in credit growth, which would transmit in the same way as a credit shock. For example, if credit growth were only responsive to interest rates ($\phi_y = 0$), then more pessimistic expectations about the likelihood of a future crisis, and therefore future output, would lead to lower interest rates and faster credit growth. In response, the CCyB would optimally tighten according to (A.37) by $\frac{dk_1}{dE_1^{ps} y_2} = \left(\frac{\phi_i}{\sigma}\right) \frac{dk_1}{d\xi_1^B}$. From (A.22), this would lead to a further reduction in optimal interest rates.

The quantitative magnitudes of these changes are very small in our benchmark calibration, however. Even an extremely large increase in the perceived annual crisis probability of 5 percentage points would only be equivalent to that of a credit shock that increased cumulative three-year real credit growth by 0.51 percentage point, or 0.17 percentage point per year. Assuming $\phi_y > 0$, such that credit growth also fell endogenously with lower future output expectations, then the increase in credit growth and the optimal policy response of the CCyB would be attenuated further still.

A.3.2 Endogenous Private-Sector Expectations

We next show that our main results are little changed in an extended version of the model that can nest both our model with exogenous private-sector expectations and a model where the private sector has rational expectations and the same information as the policymaker. Maintaining the equation for credit growth given by (A.34), and continuing to explore only output expectations, we can generalize our model by assuming that there are both good and bad credit booms, as in Gorton and Ordoñez (2019). Given this assumption, we can generalize the true, unobservable crisis probability equation (A.6) to

$$\gamma_1 = \frac{\exp(h_0 + h_B^G B_1^G + h_B^B B_1^B + h_k k_1)}{1 + \exp(h_0 + h_B^G B_1^G + h_B^B B_1^B + h_k k_1)}, \tag{A.38}$$

where B_1^G is good credit growth, B_1^B is bad credit growth, and $h_B^B > h_B^G = 0$.

If we assume that neither the policymaker nor the private sector are able to differentiate ex ante between good and bad credit growth, then this reduces to Equation (A.6), where h_B in our benchmark can be interpreted as the probability-weighted average of h_B^B and h_B^G.

This equation can capture our benchmark model where the private-sector places an exogenous probability on the likelihood of a future crisis if we assume that $E_1^{ps} h_B = h_B^G = 0$ and $E_1^{ps} h_k = 0$. The private sector thinks that all credit growth is good credit growth, and does not internalize that it may be bad credit growth and increase the likelihood of a financial crisis. Given that, it is intuitive that the private sector would expect that the crisis probability would be unaffected by changes in the CCyB.[41]

The opposite extreme, of allowing the private sector to have the same information as the policymaker about the likelihood of a credit boom being good or bad, would imply that $E_1^{ps} h_B = h_B$, $E_1^{ps} h_k = h_k$, and

$$E_1^{ps} y_2 = \gamma_1 y_{2,c} + (1 - \gamma_1) y_{2,nc}. \tag{A.39}$$

An intermediate case would allow the private sector to recognize the link between credit growth and future crises but underweight the possibility of observed credit growth being bad credit growth, which would imply that $E_1^{ps} h_B < h_B$.

Focusing on the case where the private sector has full information, the policymaker's problem is as when the private sector has exogenous expectations, to minimize (A.7) subject to (A.2)–(A.6), but now also subject to (A.39), since $E_1^{ps} y_2$ is no longer an exogenous parameter.

Following the same steps as before, but then also substituting (A.39) in place of $E_1^{ps} y_2$, and differentiating with respect to i_1 and

[41] Alternative values for exogenous private-sector expectations would be captured in this equation by varying $E_1^{ps} h_0$.

k_1 gives two different first-order necessary conditions that hold at the minimized value of L:

$$\frac{\partial L}{\partial i_1} = \left(\frac{\partial \gamma_1}{\partial i_1}(y_{2,c} - y_{2,nc}) - \sigma\right)(\kappa\pi_1 + \lambda y_1) + \frac{\partial \gamma_1}{\partial i_1}\beta((1+\zeta)E_1[L_{2,c}] - E_1[L_{2,nc}]) = 0; \tag{A.40}$$

$$\frac{\partial L}{\partial k_1} = \left(\frac{\partial \gamma_1}{\partial k_1}(y_{2,c} - y_{2,nc}) - \sigma\omega\psi\right)(\kappa\pi_1 + \lambda y_1) + \nu\psi\pi_1 + \frac{\partial \gamma_1}{\partial k_1}\beta((1+\zeta)E_1[L_{2,c}] - E_1[L_{2,nc}]) = 0. \tag{A.41}$$

The additional $(\frac{\partial \gamma_1}{\partial x_1}(y_{2,c} - y_{2,nc})$ term for each policy instrument x is positive. It derives from the fact that as well as their direct effect in dampening aggregate demand, there is now an additional offsetting channel through which higher interest rates or a higher setting for the CCyB boost demand. This arises because the reduction in the crisis probability from tighter policy leads the private sector to increase their period 2 output expectations, which leads to higher spending in period 1 as well. In the case where $\phi_y > 0$, this also dampens somewhat the impact of either policy on the crisis probability, $(\frac{\partial \gamma_1}{\partial x_1})$. This occurs because the improvement in output expectations also dampens the impact of policy on credit growth. This effect enters multiplicatively, so has no impact on the relative impact of each policy.

The remaining steps in the solution are very similar to the exogenous expectation case. Assuming Condition 1 holds, these first-order conditions are again sufficient for a global minimum, by the same logic as before. Multiplying through (A.40) by $-\frac{\frac{\partial \gamma_1}{\partial k_1}}{\frac{\partial \gamma_1}{\partial i_1}}$, and adding to (A.41) again gives a similar intratemporal optimality equation (A.13):

$$\left(\frac{\frac{\partial \gamma_1}{\partial k_1}}{\frac{\partial \gamma_1}{\partial i_1}}\sigma - \sigma\omega\psi\right)(\kappa\pi_1 + \lambda y_1) + \nu\psi\pi_1 = 0. \tag{A.42}$$

Multiplying through (A.40) by $\left(\frac{\nu\psi}{\kappa(\sigma-(\frac{\partial\gamma_1}{\partial i_1}(y_{2,c}-y_{2,nc})))} - \frac{\sigma\omega\psi-\frac{\partial\gamma_1}{\partial k_1}(y_{2,c}-y_{2,nc})}{\sigma-\frac{\partial\gamma_1}{\partial i_1}(y_{2,c}-y_{2,nc})}\right)$ and adding to (A.41) gives a similar intertemporal optimality condition to (A.17),

$$\lambda y_1\left(-\frac{\nu\psi}{\kappa}\right)=\left(\frac{\partial\gamma_1}{\partial k_1}+\frac{\partial\gamma_1}{\partial i_1}\left(\frac{\nu\psi}{\kappa(\sigma-(\frac{\partial\gamma_1}{\partial i_1}(y_{2,c}-y_{2,nc})))}\right.\right.$$
$$\left.\left.-\frac{\sigma\omega\psi-\frac{\partial\gamma_1}{\partial k_1}(y_{2,c}-y_{2,nc})}{\sigma-\frac{\partial\gamma_1}{\partial i_1}(y_{2,c}-y_{2,nc})}\right)\right)\left(-\frac{\partial L}{\partial\gamma_1}\right), \quad \text{(A.43)}$$

where the minor differences with (A.17) arise due to the additional endogenous effects on aggregate demand from the effects of policy on the future crisis probability.

The main change to our results when private-sector expectations respond endogenously is to the substitutability between different instruments.

Differentiating (A.22) now gives

$$\frac{di_1}{dk_1}=\frac{\kappa}{\sigma(\kappa^2+\overline{\lambda})}\nu\psi-\omega\psi+\frac{1}{\sigma}\frac{dE_1^{ps}y_2}{dk_1}. \quad \text{(A.44)}$$

Differentiating (A.39) with respect to k_1 gives

$$\frac{dE_1^{ps}y_2}{dk_1}=(y_{2,c}-y_{2,nc})\left(\frac{\partial\gamma_1}{\partial k_1}+\frac{\partial\gamma_1}{\partial i_1}\frac{di_1}{dk_1}+\frac{\partial\gamma_1}{\partial E_1^{ps}y_2}\frac{dE_1^{ps}y_2}{dk_1}\right)$$
$$=\frac{(y_{2,c}-y_{2,nc})}{1-(y_{2,c}-y_{2,nc})\frac{\partial\gamma_1}{\partial E_1^{ps}y_2}}\left(\frac{\partial\gamma_1}{\partial k_1}+\frac{\partial\gamma_1}{\partial i_1}\frac{di_1}{dk_1}\right). \quad \text{(A.45)}$$

And substituting this into (A.44) and rearranging gives

$$\frac{di_1}{dk_1}=$$
$$\frac{\left(\sigma-(y_{2,c}-y_{2,nc})\sigma\frac{\partial\gamma_1}{\partial E_1^{ps}y_2}\right)\left(\frac{\kappa}{\sigma(\kappa^2+\overline{\lambda})}\nu\psi-\omega\psi\right)+(y_{2,c}-y_{2,nc})\frac{\partial\gamma_1}{\partial k_1}}{\sigma-(y_{2,c}-y_{2,nc})(\sigma\frac{\partial\gamma_1}{\partial E_1^{ps}y_2}+\frac{\partial\gamma_1}{\partial i_1})}. \quad \text{(A.46)}$$

As long as the marginal impact of higher interest rates is to reduce current demand ($\sigma > (y_{2,c} - y_{2,nc})\frac{\partial \gamma_1}{\partial i_1}$), then the denominator of this expression is positive. And since $\left(\sigma - (y_{2,c} - y_{2,nc})\sigma \frac{\partial \gamma_1}{\partial E_1^{ps} y_2}\right)$ and $(y_{2,c} - y_{2,nc})\frac{\partial \gamma_1}{\partial k_1}$ are both positive, then $\left(\frac{\kappa}{\sigma(\kappa^2+\overline{\lambda})}\nu\psi - \omega\psi\right) > 0$, which ensures that the instruments are complements in the exogenous expectation model, is also sufficient to imply that the expression is positive and that the instruments are complements under endogenous expectations. The condition is not a necessary one, however, so there is a region of the parameter space where the instruments are substitutes under exogenous expectations but become complements under endogenous private-sector expectations. Intuitively, this occurs because expectations temper the negative impact of the CCyB on demand, and make it more likely that its inflationary impact on supply dominates, requiring interest rates to increase at the same time.

Appendix B. Robustness

Many of the parameters we use to calibrate our model are highly uncertain. Table B.1 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 1 pp increase in the CCyB reduces potential supply by 0.01 percent, equal to the lower end of the range reported in Brooke et al. (2015). Compared with the benchmark calibration of $\nu = 0.4$ (repeated for convenience 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 percent to around 0.05 percent, 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 3.8 pp relative to 2.2 pp in the benchmark calibration.

Table B.1. 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 ($v = 0.05$)	0.02	0.001	5.1	0.04	0.41	2.22	0.14
(iii) Larger Supply Cost of CCyB ($v = 1$)	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 ($v = 0.05$)	0.08	0.004	5.4	0.05	2.20	3.80	0.19
(xi) Larger Supply Cost of CCyB ($v = 1$)	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

Note: The table presents results obtained by running a stochastic simulation of the 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 percent of losses incurred in the event of a financial crisis occurring in period 2, also assuming that $\zeta = 0$.

Rows (iii) and (xi) show the results with a higher supply cost of $\nu = 1$, implying that a 1 pp increase in the CCyB reduces potential output by 0.2 percent, around twice as high as the median estimate reported in BCBS (2010a), 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. 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 sensitive 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 deviation 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 (13.5 pp rather than 5.4 pp), 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 3.32 pp compared with 2.20 pp in the benchmark).

The results are somewhat more affected if credit has a very large spread elasticity. In rows (vi) and (xiv) it is set almost eight 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 illustrate this, rows (vii) and (xv) of Table B.1 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 1.77 pp compared with 1.45 pp in the benchmark calibration. This only reduces the standard deviation of credit growth by 0.1 pp, however, such that the median crisis probability is around 1.5 pp 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 percent versus 0.74 percent in the full stochastic simulation), without increasing the volatility of period 1 inflation or output.

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