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Risky bank lending and countercyclical capital buffers ☆

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A R T I C L E I N F O

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A B S T R A C T

We study the properties of a monetary economy with an essential role for risky bank lending. Banks issue deposits and lend to entrepreneurs. Because banks' lending rate cannot be made contingent on aggregate shocks, and because banks face capital adequacy regulations, they require a capital buffer against loan losses. Capital adequacy regulations are modeled on the Basel-III rules, including a minimum capital adequacy ratio, an endogenous capital conservation buffer, and a countercyclical capital buffer. We find that a countercyclical capital buffer leads to a significant increase in welfare. It also reduces the need for countercyclical adjustments in policy interest rates.

1. Introduction

Macrofinancial linkages have been a major aspect of the financial and real crisis that started to affect the world economy in 2007. The financial sector was involved in triggering the crisis, and also in affecting the transmission of the initial shocks to the rest of the economy. This has led to a major rethink in economics, which previously tended to downplay the importance of the financial sector for macroeconomic developments. One of the results was a search for appropriate theoretical models of banks and of macroprudential policies such as the Basel-III regime. Some building blocks were available, such as the seminal work on corporate balance sheets and the financial accelerator of Bernanke et al. (1999). But there was very little pre-existing work on banks that was suitable for incorporation into macroeconomic models.

This has started to change since 2007, but much work remains to be done. Surveys of frictions in models of banking are presented in Gertler and Kiyotaki (2010, 2013) and Christiano and Ikeda (2011, 2013).[1] Important recent contributions to the literature on macroprudential policy include Curdia and Woodford (2010), Gerali et al. (2010), Pariès et al. (2011), Gertler and Karadi

☆ The views expressed in this paper are those of the authors and do not necessarily represent those of the Bank of England or OG Research.
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[1] Bernanke et al. (1999) and this paper rely on asymmetric information and costly state verification to model financial frictions. Gertler and Karadi (2011) and Meh and Moran (2010) are models of moral hazard.

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(2011), Kollmann et al. (2011), Angeloni and Faia (2013), Christiano et al. (2014), Cecchetti and Kohler (2014), Quint and Rabanal (2014), Angelini et al. (2015), and Brzoza-Brzezina et al. (2015).

This paper is a contribution to that theoretical literature. It develops a model of corporate bank loans that are risky because the loan contract specifies an interest rate on performing loans that is not state-contingent. This means that banks can make loan losses if a larger number of loans defaults than what was expected at the time of setting the lending rate. Banks face costs of violating capital adequacy regulations that are designed to replicate the main features of the Basel-III framework, including a minimum capital adequacy ratio (MCAR), an additional capital conservation buffer, and a countercyclical capital buffer (CCCB) that can be, and in several countries has been, introduced at the discretion of national authorities. A detailed evaluation of the macroeconomic and welfare consequences of a CCCB is the main objective of this paper. We show that without a CCCB banks respond to sudden loan losses by quickly and significantly raising their lending rate in order to rebuild their net worth, with strong adverse effects on the real economy. By contrast, with a CCCB capital requirements can be temporarily relaxed during times of macroeconomic stress, leading to smaller increases in lending rates and less severe contractions of the real economy. Because such macroprudential policies do not operate in isolation, the paper studies their properties jointly with those of conventional central bank interest rate rules. The metric for policy effectiveness is household welfare, which is evaluated by way of joint grid searches over the coefficients of monetary and macroprudential policy rules.

We find that the welfare gains that can be derived from well-designed countercyclical macroprudential rules, at over 0.20% of steady state consumption, are large by the standards of this literature, and they grow with the importance of shocks to the creditworthiness of corporate borrowers, which have recently been found to be important in the literature. The welfare gains from using the policy rate in a countercyclical fashion are similar to, or perhaps a little larger than, what has been found elsewhere. Finally, a CCCB significantly reduces the need for countercyclical adjustments in the policy rate.

Our modeling framework has the following key features: First, *banks are lenders* rather than holders of risky equity. Gertler and Karadi (2011) and Angeloni and Faia (2013) make the latter assumption, which is more appropriate for shadow banks than for commercial banks. This distinction is important, because equity, which is subject to price risk, and loans, which are subject to credit risk, have different implications for macroeconomic transmission channels.[2]

Second, *bank lending is endogenously risky*. In several existing models, if lending risk exists, it is idiosyncratic and fully diversifiable. To give rise to endogenous non-diversifiable risk, we modify the traditional financial accelerator framework of Carlstrom and Fuerst (1997) and Bernanke et al. (1999),[3] by assuming that the lending interest rates specified in debt contracts cannot be made contingent on future aggregate outcomes.

Third, *banks have their own net worth* that acts as a shock absorber for lending losses. A number of other papers, such as Christiano et al. (2014) or Curdia and Woodford (2010), explain interactions between the real and financial sectors by considering how the price of credit affects real variables, while the financial sector exhibits zero net worth, both ex ante and ex post. While this yields many critical insights, it precludes an analysis of macroprudential capital adequacy regulation.

Fourth, *bank capital is subject to regulation*, and regulation is a critical factor in determining banks' choice of capital. Moreover, capital regulation is not a continuously binding constraint, as in van den Heuvel (2008) and several other papers in the literature. We rather model regulation as a system of penalties that is imposed on banks in case they fall below the regulatory minimum. Such penalties then create behavioral incentives for banks to choose endogenous regulatory capital buffers under uncertainty, an idea first advocated by Milne (2002). Capital buffers are an important empirical regularity observed in virtually all banking systems, as documented by Jokipii and Milne (2008). They are also a key component of Basel-III, in the form of the fixed capital conservation buffer and the variable CCCB. In our model, these buffers are an equilibrium phenomenon that results from the interaction of aggregate shocks, macroprudential regulation and debt contracts.[4]

Fifth, *acquiring fresh capital is subject to market imperfections*. This is a necessary condition for capital adequacy regulation to have non-trivial effects, and for capital buffers to exist. This fact is emphasized by van den Heuvel (2002), and examples of partial equilibrium models with such imperfections include Estrella (2004) with dynamic quadratic adjustment costs, or Peura and Keppo (2006) with a recapitalization delay. We use the "extended family" approach of Gertler and Karadi (2011), whereby bankers (and also non-financial entrepreneurs) transfer part of their accumulated net worth to the household budget constraint at an exogenously fixed rate. This is closely related to the original approach of Bernanke et al. (1999), and to the dividend policy function of Aoki et al. (2004).

The rest of the paper is organized as follows. Section 2 presents the model. Section 3 discusses the results. Section 4 concludes.

[2] Chrétien and Lyonnet (2014) demonstrate that the main reason for the contraction in the balance sheet of the overall financial system during the 2008/2009 financial crisis was cutbacks in lending by commercial banks, rather than sales of securities by shadow banks to non-banks.

[3] Both of these papers focus on corporate bank lending that finances capital investment, and abstract from bank lending to households. We follow this tradition to keep the exposition simple. This does however have implications for the ability of the model to match certain moments of the data, as we will explain below.

[4] In the existing literature, Gerali et al. (2010) have created time-varying excess capital by using a quadratic cost short-cut. The same approach is followed by Pariès et al. (2011).

2. The model

We consider a closed economy that consists of representative households, capital goods producers, capital investment funds, banks, manufacturers and a government. A full description of their respective optimization problems is contained in a separate Technical Appendix. The economy grows at the constant exogenous growth rate $x = T_t/T_{t-1}$, where T_t is labor augmenting technology. The model's real variables, say z_t, therefore have to be rescaled by T_t, where we will use the notation $\check{z}_t = z_t/T_t$. The steady state of $\check{z}_t$ is denoted by $\bar{z}$.

2.1. Households

The utility of a representative household, indexed by i, at time t depends on the consumption habit $c_t(i) - \nu c_{t-1}$, where $c_t(i)$ is the individual consumption and c_t is the aggregate per capita consumption, and where consumption is a Dixit–Stiglitz CES aggregate over varieties supplied by manufacturers, with elasticity of substitution θ. Utility also depends on labor hours $h_t(i)$ and on real deposit money balances $D_t(i)/P_t$, where $D_t(i)$ is nominal deposits and P_t is the consumer price index. Lifetime expected utility at time 0 of an individual household is

$$E_0 \sum_{t=0}^{\infty} \beta^t \left\{ S_t^c \left(1 - \frac{\upsilon}{x}\right) \log(c_t(i) - \upsilon c_{t-1}) - \psi \frac{h_t(i)^{1+1/\eta}}{1 + \frac{1}{\eta}} + \zeta \log\left(\frac{D_t(i)}{P_t}\right) \right\}, \tag{1}$$

where β is the discount factor, S_t^c is a shock to the marginal utility of consumption, υ determines the degree of habit persistence, η is the labor supply elasticity, and ψ and ζ fix the utility weights of labor disutility and real deposit money balances, respectively. All households have identical initial endowments and behave identically. The household index i is therefore only required for the distinction between $c_t(i)$ and c_{t-1}, and will henceforth be dropped.

As explained in more detail in the Technical Appendix, each household represents an extended family that consists of three types of members, workers, entrepreneurs and bankers. Entrepreneurs and bankers enter and exit their occupations for random lengths of time, after which they revert to being workers, and with the population shares of the three groups remaining constant over time. There is perfect consumption insurance within each household. Workers supply labor, and their wages are returned to the household in each period. Each entrepreneur (banker) manages a capital investment fund (bank), with a small initial start-up net worth provided by the household, and during his tenure retains accumulated net worth within the capital investment fund (bank). When his period as an entrepreneur (banker) ends, he transfers his net worth back to the household. This can be shown to imply that entrepreneurs (bankers) in aggregate pay out a fixed fraction δ^k (δ^b) of aggregate net worth as dividends. The implication is that while the household ultimately owns both capital investment funds and banks, net worth cannot be freely injected into or withdrawn from these entities. That in turn means that net worth and leverage matter for capital investment funds' and banks' decisions.

Households can hold nominal domestic government debt B_t and nominal bank deposits D_t, with real debt and deposits given by $b_t = B_t/P_t$ and $d_t = D_t/P_t$, and with the time subscript t denoting financial claims held from period t to period $t+1$. The gross nominal interest rate on government debt held from t to $t+1$ is i_t, and the corresponding rate for bank deposits is $i_{d,t}$. We denote gross consumer price inflation by $\pi_t = P_t/P_{t-1}$, and gross ex-post real interest rates on government bonds and bank deposits by $r_t = i_{t-1}/\pi_t$ and $r_{d,t} = i_{d,t-1}/\pi_t$. In addition to interest income households receive labor income, dividend distributions, and lump-sum incomes earned in the administration of corporate bankruptcies Υ_t^e. Real labor income equals $w_t h_t$, where $w_t = W_t/P_t$ is the real wage rate. Real dividend distributions equal $\int_0^1 \Pi_t^m(j)dj + \int_0^1 \Pi_t^k(j)\, dj + \delta^k n_t^k + \delta^b n_t^b$, where $\Pi_t^m(j)$ and $\Pi_t^k(j)$ are, respectively, real profits of individual manufacturers and capital goods producers, who each have unit mass and are indexed by j, $\delta^k n_t^k$ are dividends from capital investment funds, and $\delta^b n_t^b$ are dividends from banks. Finally, households pay lump-sum taxes τ_t to the government. The household's budget constraint in real terms is

$$\begin{aligned} b_t + d_t &= r_t b_{t-1} + r_{d,t} d_{t-1} - c_t - \tau_t \\ &\quad + w_t h_t + \int_0^1 \Pi_t^m(j)\, dj + \int_0^1 \Pi_t^k(j)\, dj + \delta^k n_t^k + \delta^b n_t^b + \Upsilon_t^e. \end{aligned} \tag{2}$$

The household maximizes (1) subject to (2). Denoting the multiplier of (2) by λ_t, and normalizing by T_t, we obtain the following first-order conditions for c_t, h_t, B_t and D_t:

$$\frac{S_t^c \left(1 - \frac{\upsilon}{x}\right)}{\check{c}_t - \frac{\nu}{x}\check{c}_{t-1}} = \check{\lambda}_t, \tag{3}$$

$$\psi h_t^{1/\eta} = \check{\lambda}_t \check{w}_t, \tag{4}$$

$$\check{\lambda}_t = \frac{\beta}{x} i_t E_t \left(\frac{\check{\lambda}_{t+1}}{\pi_{t+1}}\right), \tag{5}$$

$$\check{\lambda}_t = \frac{\beta}{x} i_{d,t} E_t \left(\frac{\check{\lambda}_{t+1}}{\pi_{t+1}} \right) + \frac{\zeta}{\check{d}_t}. \tag{6}$$

2.2. Capital goods producers

Capital goods producers produce the capital stock used by capital investment funds. They are competitive price takers, and are owned by households, who receive their net cash flow as lump-sum transfers in each period. The time line for the capital stock is as follows: capital investment funds enter period t with capital inherited from period $t-1$. Manufacturers then rent the capital from capital investment funds to produce output, and the capital stock depreciates. Next, capital goods producers purchase the depreciated capital $K_{t-1}(j)$ from capital investment funds, and investment goods $I_t(j)$ from manufacturers, to produce new installed capital $K_t(j)$, where $K_t(j) = K_{t-1}(j) + I_t(j)$. The capital goods producer then sells this capital, still in period t, to capital investment funds, for use in next period's production. Production of capital goods is subject to investment adjustment costs

$$G_{I,t}(j) = \frac{\phi_I}{2} I_t \left(S_t^I \frac{(I_t(j)/x)}{I_{t-1}(j)} - 1 \right)^2, \tag{7}$$

where the scale variable I_t is aggregate investment and S_t^I is a shock to investment demand. The nominal price level of previously installed capital is denoted by Q_t. Since the marginal rate of transformation from previously installed to newly installed capital is one, the price of new capital also equals Q_t. The optimization problem is to maximize the present discounted value of dividends by choosing the level of new investment $I_t(j)$:

$$\max_{\{I_t(j)\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t \lambda_t \Pi_t^k(j),$$
$$\Pi_t^k(j) = \left[q_t(K_{t-1}(j) + I_t(j)) - q_t K_{t-1}(j) - I_t(j) - G_{I,t}(j) \right]. \tag{8}$$

In equilibrium all capital goods producers behave identically, so that the index j can henceforth be dropped. The solution to the optimization problem, in real normalized form, is

$$q_t = 1 + \phi_I S_t^I \left(\frac{\check{I}_t}{\check{I}_{t-1}} \right) \left(S_t^I \frac{\check{I}_t}{\check{I}_{t-1}} - 1 \right) - E_t \beta \frac{\check{\lambda}_{t+1}}{\check{\lambda}_t} \phi_I S_{t+1}^I \left(\frac{\check{I}_{t+1}}{\check{I}_t} \right)^2 \left(S_{t+1}^I \frac{\check{I}_{t+1}}{\check{I}_t} - 1 \right). \tag{9}$$

The stock of aggregate physical capital evolves as

$$k_t = (1-\Delta) k_{t-1} + I_t, \tag{10}$$

where Δ is the depreciation rate, $k_t = K_t$ and $(1-\Delta)k_{t-1} = K_{t-1}$.

2.3. Capital investment funds

Capital investment funds have unit mass and are indexed by j. They purchase the physical capital stock from capital goods producers at the end of period t, and rent it to manufacturers, for use in production, in period $t+1$. Each capital investment fund j finances its end of period t capital holdings (at current market prices) $Q_t k_t(j)$ with a combination of its end of period t net worth $N_t^k(j)$ and bank loans $L_t(j)$. In real terms, its balance sheet constraint is given by

$$q_t k_t(j) = n_t^k(j) + \ell_t(j), \tag{11}$$

where $q_t = Q_t/P_t$, $n_t^k(j) = N_t^k(j)/P_t$ and $\ell_t(j) = L_t(j)/P_t$. After the capital purchase, at the beginning of period $t+1$, each capital investment fund draws an idiosyncratic shock[5] which changes $k_t(j)$ to $\omega_{t+1}^k k_t(j)$, where ω_{t+1}^k is a lognormal random variable distributed independently over time and across capital investment funds, with $E(\omega_{t+1}^k) = 1$ and $Var(\ln(\omega_{t+1}^k)) = (\sigma_{t+1}^k)^2$. The standard deviation σ_{t+1}^k is itself a stochastic process that will play a key role in our analysis. We will refer to it as the borrower riskiness shock. The cumulative distribution function of ω_{t+1}^k at time t is given by $\Pr(\omega_{t+1}^k \le x) = F_t^k(x)$, and the corresponding density function by $f_t^k(x)$.

Defining the real rental rate of capital as $r_{k,t}$, the capital investment fund's ex-post real return to capital between periods $t-1$ and t is given by

$$ret_{k,t} = \frac{r_{k,t} + (1-\Delta) q_t}{q_{t-1}}. \tag{12}$$

We assume that the capital investment fund negotiates a debt contract with the bank. This contract specifies a nominal loan amount $L_t(j)$ and a gross nominal retail rate of interest $i_{r,t}$, which must be paid if ω_{t+1}^k is sufficiently high for the capital

[5] From the point of view of bankers, borrowers are therefore identical ex-ante but different ex-post. The model is therefore silent on ex-ante borrower differences, such as the difference between opaque and transparent borrowers stressed by Dell'Ariccia and Marquez (2001).

investment fund to avoid bankruptcy. The critical difference between our model and those of Bernanke et al. (1999) and Christiano et al. (2014) is that the interest rate $i_{r,t}$ is assumed to be pre-committed in period t, rather than being determined in period $t+1$ after the realization of $t+1$ aggregate shocks.[6] The latter assumption insures zero ex-post profits for banks at all times, while under our debt contract banks make zero expected profits, but realized ex-post profits generally differ from zero. Capital investment funds who draw ω_{t+1}^k below a cutoff level $\overline{\omega}_{t+1}^k$ cannot pay the interest charges $i_{r,t}L_t(j)$ out of their capital earnings and go bankrupt. They must hand over their entire capital stock to the bank, but the bank can only recover a fraction $(1-\xi)$ of the value of that capital. The remaining fraction represents monitoring costs, which are assumed to be paid out to households in a lump-sum fashion, as remuneration for work performed in the administration of bankruptcies. The ex-ante cutoff productivity level is determined by equating, at $\omega_{t+1}^k = \overline{\omega}_{t+1}^k$, the gross interest charges due in the event of continuing operations to the gross idiosyncratic return on the capital investment fund's capital stock. The ex-post cutoff productivity level is

$$\overline{\omega}_t^k = \frac{r_{r,t}\check{\ell}_{t-1}(j)}{ret_{k,t}q_{t-1}\check{k}_{t-1}(j)}. \tag{13}$$

Denoting the wholesale real lending rate that banks would charge to notional zero-risk borrowers by $r_{\ell,t}$, banks' ex-ante zero profit constraint, in real terms, is then given by

$$0 = E_t\left\{r_{\ell,t+1}\ell_t(j) - \left[\left(1-F_t^k(\overline{\omega}_{t+1}^k)\right)r_{r,t+1}\ell_t(j) \right.\right.$$
$$\left.\left. + (1-\xi)\int_0^{\overline{\omega}_{t+1}^k} q_t k_t(j) ret_{k,t+1}\omega_{t+1}^k f_t^k(\omega_{t+1}^k) d\omega_{t+1}^k\right]\right\}. \tag{14}$$

This states that the expected payoff to lending must equal expected wholesale real interest payments $r_{\ell,t+1}\ell_t(j)$. The first term in square brackets is the real interest income on loans to borrowers whose idiosyncratic shock exceeds the cutoff level, $\omega_{t+1}^k \geq \overline{\omega}_{t+1}^k$, and who are therefore able to service their loan at the pre-committed retail lending rate. The second term is the amount collected by the bank in case of the borrower's bankruptcy, where $\omega_{t+1}^k < \overline{\omega}_{t+1}^k$. This cash flow is based on the return $ret_{k,t+1}\omega_{t+1}^k$ on capital investment $q_t k_t(j)$, but multiplied by the factor $(1-\xi)$ to reflect a proportional bankruptcy cost ξ.

Following Bernanke et al. (1999), we adopt a number of definitions that simplify the following derivations. First, the lender's gross share in expected nominal capital earnings $Ret_{k,t+1}Q_t k_t(j)$ is $\Gamma_{t+1} = \Gamma_t(\overline{\omega}_{t+1}^k) = \int_0^{\overline{\omega}_{t+1}^k} \omega_{t+1}^k f_t^k(\omega_{t+1}^k)\, d\omega_{t+1}^k + \overline{\omega}_{t+1}^k \int_{\overline{\omega}_{t+1}^k}^{\infty} f_t^k(\omega_{t+1}^k)\, d\omega_{t+1}^k$, while the lender's monitoring costs share in expected nominal capital earnings is $\xi G_{t+1} = \xi G_t(\overline{\omega}_{t+1}^k) = \xi \int_0^{\overline{\omega}_{t+1}^k} \omega_{t+1}^k f_t^k(\omega_{t+1}^k)\, d\omega_{t+1}^k$. Then the capital investment fund's share in expected nominal capital earnings is $1-\Gamma_{t+1} = \int_{\overline{\omega}_{t+1}^k}^{\infty} \left(\omega_{t+1}^k - \overline{\omega}_{t+1}^k\right) f_t^k(\omega_{t+1}^k)\, d\omega_{t+1}^k$.

The capital investment fund's debt contract is chosen to maximize its profits, subject to zero expected bank profits. Denoting the multiplier of the participation constraint by $\tilde{\lambda}_{t+1}$, the capital investment fund's optimization problem can be written as[7]

$$\max_{k_t(j),\overline{\omega}_{t+1}^k} E_t\left\{(1-\Gamma_{t+1})\frac{ret_{k,t+1}}{r_{\ell,t+1}}\frac{q_t k_t(j)}{n_t^k(j)}\right.$$
$$\left. + \tilde{\lambda}_{t+1}\left[(\Gamma_{t+1}-\xi G_{t+1})\frac{ret_{k,t+1}}{r_{\ell,t+1}}\frac{q_t k_t(j)}{n_t^k(j)} - \frac{q_t k_t(j)}{n_t^k(j)} + 1\right]\right\}. \tag{15}$$

We obtain the following condition for the optimal loan contract:

$$E_t\left\{(1-\Gamma_{t+1})\frac{ret_{k,t+1}}{r_{\ell,t+1}} + \frac{\Gamma_{t+1}^{\omega}}{\Gamma_{t+1}^{\omega} - \xi G_{t+1}^{\omega}}\left[\frac{ret_{k,t+1}}{r_{\ell,t+1}}(\Gamma_{t+1}-\xi G_{t+1}) - 1\right]\right\} = 0. \tag{16}$$

Notice that each capital investment fund faces the same expectations for future returns $ret_{k,t+1}$, $r_{\ell,t+1}$ and $r_{r,t+1}$, and the same risk environment characterizing the functions Γ_{t+1} and G_{t+1}. Aggregation of the model over capital investment funds is therefore trivial because both borrowing and capital purchases are proportional to the capital investment fund's level of net worth. Indices j can therefore be dropped, including in Eq. (13).

Capital investment funds' aggregate net worth represents an additional state variable, whose evolution in real normalized terms is given by

$$\check{n}_t^k = \frac{r_{\ell,t}}{x}\check{n}_{t-1}^k + \left(\frac{ret_{k,t}}{x}(1-\xi G_t) - \frac{r_{\ell,t}}{x}\right)q_{t-1}\check{k}_{t-1} - \delta^k \check{n}_t^k + \check{\Lambda}_t^{\ell}, \tag{17}$$

[6] See Bernanke et al. (1999): "… conditional on the ex-post realization of R_{t+1}^k, the borrower offers a (*state-contingent*) *non-default* payment that guarantees the lender a return equal in expected value to the riskless rate."

[7] As in Bernanke et al. (1999) and Christiano et al. (2014), our setup abstracts from the fact that the ultimate owners of capital investment funds, households, have a variable intertemporal marginal rate of substitution whereby future profits are more valuable in some states of nature than in others.

where all but the last term is identical to Bernanke et al. (1999) and Christiano et al. (2014). The term $\check{\Lambda}_t^{\ell}$ represents aggregate ex-post loan losses by banks, which are given by

$$\check{\Lambda}_t^{\ell} = \frac{r_{\ell,t}}{x}\check{\ell}_{t-1} - q_{t-1}\check{k}_{t-1}\frac{ret_{k,t}}{x}(\Gamma_t - \xi G_t). \tag{18}$$

Banks' losses are therefore positive if wholesale interest expenses, which are the opportunity cost of banks' retail lending funds, exceed banks' net (of monitoring costs) share in capital investment funds' gross capital earnings. This will be the case if a larger than anticipated number of capital investment funds defaults, so that, ex-post, banks find that they have set their pre-committed retail lending rate at an insufficient level to compensate for lending losses. Of course, relative to the case of zero ex-post loan losses, banks' losses $\check{\Lambda}_t^{\ell}$ are entrepreneurs' gains, which explains why $\check{\Lambda}_t^{\ell}$ enters with a positive sign in (17).

2.4. Banks

Banks have unit mass and are indexed by j. The asset side of bank balance sheets consists of loans issued to capital investment funds, $L_t(j)$, and the liability side consists of deposits issued to households, $D_t(j)$, and of net worth $N_t^b(j)$, with $n_t^b(j) = N_t^b(j)/P_t$. Every bank is assumed to hold a fully diversified portfolio of loans, such that its share in loans to an individual borrower is equal to its share in aggregate loans. As a consequence, each bank's share in aggregate loan losses is proportional to its share in aggregate loans. In real form an individual bank's balance sheet is given by

$$\ell_t(j) = d_t(j) + n_t^b(j). \tag{19}$$

Our analysis focuses on bank solvency considerations and ignores liquidity management problems. Banks are therefore modeled as having no incentive, either regulatory or precautionary, to maintain cash reserves at the central bank. Because, furthermore, for households cash is dominated in return by bank deposits, in this economy there is no demand for government-provided real cash balances.

Banks are required to pay regulatory penalties to the government in case they violate official MCAR,[8] and therefore hold an additional buffer of net worth in order to protect themselves against penalties. Our calibration is such that the probability of banks losing their entire net worth, rather than dropping below the regulatory minimum of 8% of assets, is so small that it can be neglected in the quantitative analysis. We will demonstrate this in Section 3. The assumption that banks face pecuniary costs of falling short of MCAR introduces a discontinuity in outcomes. In any given period, a bank either remains sufficiently well capitalized, or it falls short of MCAR and must pay a penalty to the government. In the latter case, bank net worth drops further. The cost of such an event, weighted by the appropriate probability, is incorporated into the bank's optimal choice of net worth. Modeling this regulatory framework under the assumption of homogeneous banks would lead to outcomes where all banks simultaneously either pay or do not pay the penalty. A more realistic specification therefore requires a continuum of ex-ante identical (except for the scale of their operations, which is determined by their level of net worth) banks, each of which is exposed to idiosyncratic shocks, so that ex-post there is a continuum of capital adequacy ratios across banks, and a time-varying small fraction of banks have to pay penalties in each period. We model this by assuming an idiosyncratic component in the return to loans in the specification of banks' problem. This can reflect a number of individual bank characteristics, such as differing success at raising non-interest income and minimizing non-interest expenses, where the sum of these two categories has to sum to zero over all banks.

Specifically, the return on banks' loan book is subject to an idiosyncratic shock ω_{t+1}^b that is lognormally distributed, with $E(\omega_{t+1}^b) = 1$ and $Var(\ln(\omega_{t+1}^b)) = (\sigma_{t+1}^b)^2$, and with the density function and cumulative density function of ω_{t+1}^b denoted by $f_t^b(\omega_{t+1}^b)$ and $F_t^b(\omega_{t+1}^b)$. The regulatory framework stipulates that banks have to pay a real penalty of $\chi\ell_t(j)$ at time $t+1$, as a lump-sum payment to the government/regulator, if the gross return on their loan book, net of gross deposit interest expenses and loan losses, is less than a fraction γ_t of the gross return on their loan book:

$$r_{\ell,t+1}\ell_t(j)\omega_{t+1}^b - r_{d,t+1}d_t(j) - \Lambda_{t+1}^{\ell}(j) < \gamma_t r_{\ell,t+1}\ell_t(j)\omega_{t+1}^b. \tag{20}$$

Because the left-hand side equals pre-dividend (and pre-penalty) net worth at the beginning of period $t+1$, while the term multiplying γ_t equals the value of assets at the beginning of period $t+1$, γ_t represents the MCAR.[9] CCCBs will be modeled as a time-varying MCAR, under the implicit assumption of a fixed capital conservation buffer. This explains the presence of the time subscript on γ_t. We denote the ex-ante cut-off loan return below which the MCAR is breached by $\overline{\omega}_{t+1}^b$. The ex-post cutoff loan return is

$$\overline{\omega}_t^b = \frac{r_{d,t}d_{t-1}(j) + \Lambda_t^{\ell}(j)}{(1-\gamma_{t-1})r_{\ell,t}\ell_{t-1}(j)}. \tag{21}$$

[8] Furfine (2001) and van den Heuvel (2005) contain a list of such penalties, according to the Basel rules or to national legislation, such as the U.S. Federal Deposit Insurance Corporation Improvement Act of 1991.

[9] Note that in our stylized model all assets have a risk-weighting of 100%, so that there is no difference between the Basel-III capital adequacy ratio (which is calculated on the basis of risk-weighted assets) and the inverse of the Basel-III leverage ratio (which is calculated on the basis of unweighted assets).

Each bank chooses loans to maximize its pre-dividend net worth, which equals the gross return on its loan book minus the sum of gross interest on deposits, loan losses, and penalties[10]:

$$\max_{\ell_t(j)} E_t\left[r_{\ell,t+1}\ell_t(j)\omega^b_{t+1} - r_{d,t+1}d_t(j) - \Lambda^{\ell}_{t+1}(j) - \chi\ell_t(j)F^b_t(\overline{\omega}^b_{t+1})\right]. \tag{22}$$

The first-order necessary condition, in real normalized form, is given by

$$E_t\left[r_{\ell,t+1} - r_{d,t+1} - \chi\left(F^b_t\left(\overline{\omega}^b_{t+1}\right) + f^b_t\left(\overline{\omega}^b_{t+1}\right)\left(\frac{r_{d,t+1}}{(1-\gamma_t)r_{\ell,t+1}\frac{\check{\ell}_t}{\check{n}^b_t}}\right)\right)\right] = 0. \tag{23}$$

For the same reason as in the previous subsection, bank-specific indices j can be dropped, including in Eq. (21). This optimality condition states that banks' wholesale lending rate is equal to their deposit rate plus a premium term that depends on the penalty for breaching the MCAR. That term includes the penalty parameter χ and expressions that determine the likelihood of a breach. Their retail rate on the other hand is at another premium over the wholesale rate, to compensate for the bankruptcy risk of capital investment funds, as discussed in Section 2.3. An interpretation of the wholesale rate is therefore the rate that a bank would charge to a hypothetical capital investment fund (not present in the model) with zero default risk.

Banks' aggregate net worth represents an additional state variable of the model, and in real normalized terms is given by

$$\check{n}^b_t = \frac{1}{x}\left(r_{\ell,t}\check{\ell}_{t-1} - r_{d,t}\check{d}_{t-1} - \check{\Lambda}^{\ell}_t x - \chi\check{\ell}_{t-1}F^b_t(\overline{\omega}^b_t)\right) - \delta^b\check{n}^b_t. \tag{24}$$

2.5. Manufacturers

The technology of each manufacturer j is given by

$$y_t(j) = \left(S^a_t T_t h_t(j)\right)^{1-\alpha} k_{t-1}(j)^{\alpha}, \tag{25}$$

where S^a_t is a transitory shock to labor-augmenting technology. Cost minimization implies standard (normalized) input demands for labor and capital

$$h_t = (1-\alpha)\frac{mc_t}{\check{w}_t}\check{y}_t, \tag{26}$$

$$\frac{\check{k}_{t-1}}{x} = \alpha\frac{mc_t}{r^k_t}\check{y}_t, \tag{27}$$

where $mc_t = A\left(\check{w}_t/S^a_t\right)^{1-\alpha}\left(r^k_t\right)^{\alpha}$, $A = \alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)}$, and where manufacturer-specific indices have been dropped because in equilibrium all manufacturers' cost minimization conditions are identical. We denote the price of product variety j by $P_t(j)$. Manufacturers maximize the present discounted value of real future profits $\Pi^m_t(j)$. The latter equal real revenue $(P_t(j)/P_t)y_t(j)$ minus real expenditures, specifically real marginal costs $mc_t y_t(j)$ and a Rotemberg (1982)-style quadratic price adjustment cost that allows for a nonzero central bank inflation target $\overline{\pi}$. The optimal price setting problem is

$$\max_{\{P_t(j)\}_{t=0}^{\infty}} \quad E_0\sum_{t=0}^{\infty}\beta^t\lambda_t\Pi^m_t(j),$$

$$\Pi^m_t(j) = \frac{P_t(j)}{P_t}y_t(j) - mc_t y_t(j) - \frac{\phi_p}{2}y_t\left(\frac{P_t(j)}{P_{t-1}(j)} - \overline{\pi}\right)^2, \tag{28}$$

subject to $y_t(j) = y_t\left(P_t(j)/P_t\right)^{-\theta}$, which is the demand function for varieties derived from Dixit–Stiglitz demands for aggregate output. We assume that households, investors and the government demand an identical aggregate over varieties. Letting $\mu = \theta/(\theta-1)$, the normalized optimality condition, again after dropping manufacturer-specific indices, is

$$mc_t\mu - 1 = \phi_p(\pi_t - \overline{\pi})\pi_t - \beta\frac{\check{\lambda}_{t+1}}{\check{\lambda}_t}\frac{\check{y}_{t+1}}{\check{y}_t}\phi_p(\pi_{t+1} - \overline{\pi})\pi_{t+1}. \tag{29}$$

[10] The same comments as in footnote 7 apply to this optimization problem.

2.6. Government

Government spending, normalized by technology, is assumed to be exogenous and equal to a fixed fraction s_g of steady state GDP $\overline{y}$ multiplied by a shock S_t^g:

$$\check{g}_t = S_t^g s_g \overline{y}. \tag{30}$$

The government receives the penalty payments of banks that violate the MCAR, $\check{\Upsilon}_t^b = (\chi/x)\check{\ell}_{t-1} F_t^b(\overline{\omega}_t^b)$. The government only levies lump-sum taxes and households are assumed to be Ricardian. We therefore assume for simplicity that initial government debt is zero, and that the government balances its budget in each period:

$$\check{g}_t = \check{\tau}_t + \check{\Upsilon}_t^b. \tag{31}$$

Monetary policy is given by a forward-looking interest rate rule, with inflation target $\overline{\pi}$:

$$\begin{aligned} i_t &= (i_{t-1})^{m_i} \left(\frac{x}{\beta}\overline{\pi}\right)^{(1-m_i)} \left(\frac{\pi_{4,t+3}}{(\overline{\pi})^4}\right)^{(1-m_i)m_\pi} \left(\frac{\check{y}_t}{\overline{y}}\right)^{(1-m_i)m_y} \left(\frac{\check{y}_t}{\check{y}_{t-1}}\right)^{(1-m_i)m_{ygr}} \\ &\quad \left(\frac{\check{\ell}_t}{\overline{\ell}}\right)^{(1-m_i)m_\ell} \left(\frac{\check{\ell}_t/\check{y}_t}{\overline{\ell}/\overline{y}}\right)^{(1-m_i)m_d} S_t^i, \\ \pi_{4,t} &= \pi_t \pi_{t-1} \pi_{t-2} \pi_{t-3}. \end{aligned} \tag{32}$$

The first four coefficients of this rule are the conventional interest rate smoothing coefficient m_i and the feedback coefficients m_π, m_y and m_{ygr} on inflation expectations,[11] the output gap and output growth. The last two coefficients, m_ℓ and m_d, represent responses to deviations of the loan stock or the loans-to-output ratio from their trends. S_t^i is a monetary policy shock. We have verified that changing the inflation forecast horizon in this rule makes only a small difference to our main results. Optimizing the coefficients m_i, m_π, m_y, m_ℓ and m_d is the first component of our welfare analysis.

Macroprudential policy varies the MCAR coefficient γ_t according to the rule[12]

$$\gamma_t = (\gamma_{t-1})^{p_\gamma} (\overline{\gamma})^{1-p_\gamma} \left(\frac{\check{y}_t}{\overline{y}}\right)^{(1-p_\gamma)p_y} \left(\frac{\check{\ell}_t}{\overline{\ell}}\right)^{(1-p_\gamma)p_\ell} \left(\frac{\check{\ell}_t/\check{y}_t}{\overline{\ell}/\overline{y}}\right)^{(1-p_\gamma)p_d}. \tag{33}$$

This rule represents a number of elements of the Basel-III regime. The steady state MCAR is represented by $\overline{\gamma}$. The capital conservation buffer, whereby the actual steady state capital adequacy ratio (CAR) exceeds $\overline{\gamma}$, is optimally chosen by individual banks, taking into account the size of regulatory penalties that apply when their CAR drops below the MCAR. The CCCB is implemented by allowing the MCAR γ_t to increase with deviations of either output, the loan stock or the loans-to-output ratio from their trends. This is intended to lead to the accumulation of additional capital buffers during booms, and to the release of capital buffers during contractions. In this paper we focus exclusively on the properties of this CCCB, while taking the steady state MCAR $\overline{\gamma}$ and the steady state capital conservation buffer as given.[13] Optimizing the coefficients p_γ, p_y, p_ℓ and p_d is the second component of our welfare analysis.

2.7. Equilibrium

In equilibrium all agents maximize their objective functions, and the goods market clears[14]:

$$\check{y}_t = \check{c}_t + \check{I}_t + \check{g}_t. \tag{34}$$

The model's shock processes $z_t \in \left\{S_t^a, S_t^c, S_t^I, S_t^g, S_t^i, \sigma_t^k\right\}$ are given by

$$\log(z_t) = (1-\rho_z)\log(\overline{z}) + \rho_z \log(z_{t-1}) + \varepsilon_t^z. \tag{35}$$

2.8. Calibration and model solution

We calibrate our model at the quarterly frequency for the United States. Calibration of the steady state, and simulations of impulse responses, are performed in TROLL, the moments of the model are computed in Dynare, and welfare is computed in Dynare++. Target values and parameters of our steady state calibration are shown in Table 1a.

The steady state real growth rate and inflation rate are both calibrated at 2% per annum. Following Smets and Wouters (2003), the habit parameter υ is set to 0.7. The labor supply elasticity η is fixed at 1, a common assumption in the monetary

[11] The incorporation of a forward-looking inflation term reflects the practice of many central banks of targeting expectations of inflation rather than current inflation. Forward-looking specifications are therefore used in many policy models, see e.g. Carabenciov et al. (2013).

[12] We only allow for one of the three gap-coefficients p_y, p_ℓ and p_d to be nonzero at any one time.

[13] Many papers in the recent literature have followed a similar approach. See Angelini et al. (2011), Christensen et al. (2011), Gelain et al. (2013), Kannan et al. (2012), and Lambertini et al. (2013).

[14] An equivalent condition holds for each goods variety.

Table 1a
Structural parameters.

Variable	Baseline	Symbol	Value
	Growth rates		
Real growth rate	2% p.a.	x	1.02
Inflation rate	2% p.a.	$\overline{\pi}$	1.02
	Preferences and technologies		
Consumption habit		υ	0.7
Labor supply elasticity		η	1
Investment adj. cost		ϕ_I	2
Price adj. cost		ϕ_P	200
Price markup	10%	μ	1.1
	Ratios		
Capital income share	40%	α	0.34
Investment/GDP	19%	Δ	0.01534
Gov. spending/GDP	18%	s_g	0.18
	Balance sheets		
Corporate leverage	100%	δ^k	0.0204
Bank MCAR	8%	$\overline{\gamma}$	0.08
Bank capital conservation buffer	2.5%	δ^b	0.0146
	Real interest rates		
Real policy rate	3.00% p.a.	β	0.9975
Real deposit rate	2.75% p.a.	ζ	0.0042
Real wholesale lending rate	3.30% p.a.	χ	0.0033
Real retail lending rate	4.30% p.a.	ξ	0.1771
	Failure rates		
Corporate bankruptcy rate	1% p.q.	$\overline{\sigma}^k$	0.2836
Bank MCAR violation rate	2% p.q.	σ^b	0.0140
	Monetary policy rule		
Interest rate smoothing		m_i	0.7
Inflation feedback		m_π	2.0
Output growth feedback		m_{ygr}	0.25

business cycle literature. The investment adjustment cost parameter, at $\phi_I = 2$, is close to Christiano et al. (2005). The price adjustment cost parameter is set to $\phi_p = 200$. Together with the assumption that the gross markup equals $\mu = 1.1$, this is equivalent to assuming that the average duration of price contracts equals roughly 5 quarters in a model with Calvo (1983) pricing and Yun (1996) indexation. The cost share of private capital α, the depreciation rate Δ, and the parameter s_g are calibrated to obtain a steady state capital income share (including markups) of 40%, a steady state private investment to GDP ratio of 19%, and a steady state government spending to GDP ratio of 18%.

The parameters δ^k, δ^b, $\overline{\sigma}^k$, σ^b, ξ, χ, $\overline{\gamma}$ and ζ in capital investment funds', banks' and households' equilibrium conditions are endogenized by fixing a number of steady state balance sheet ratios and interest rate margins. Capital investment funds' steady state leverage ratio, meaning their ratio of debt to net worth, is fixed at 100% using the dividend payout parameter δ^k. This value is well supported by the data for non-financial corporate leverage (Ueda and Brooks, 2011). Banks' steady state capital ratios are calibrated to reflect the Basel-III regime. First, in steady state penalties start to apply to banks that drop below the Basel-III 8% MCAR, which requires setting $\overline{\gamma} = 0.08$. Second, the dividend payout parameter δ^b is calibrated such that the steady state CAR equals 10.5%, replicating the 2.5% capital conservation buffer called for under Basel-III.

The steady state real policy interest rate equals 3.00% p.a., by choosing the corresponding value of the discount factor β. The real deposit rate equals 2.75% p.a., with the 25 basis points discount to the real policy rate due to a positive utility weight ζ of deposits in the utility function. The steady state wholesale real lending rate equals 3.3% p.a., with the 55 basis points margin over the real deposit rate due to regulatory penalty costs χ that equal 0.33% of the outstanding loan volume. The steady state retail real lending rate equals 4.3% p.a., with the 100 basis points margin over the wholesale rate due to positive bankruptcy monitoring costs ξ. These 100 basis points represent the model's external finance premium. The Bernanke et al. (1999) measure of the external finance premium is based on an average of the retail lending rate and of loan recoveries from defaulting borrowers. In our steady state this premium equals 65 basis points. The steady state share of capital investment funds that goes bankrupt in each quarter is calibrated at 1%, using the riskiness parameter $\overline{\sigma}^k$, while the steady state share of banks that drop below the MCAR in each quarter is calibrated at 2%, using the riskiness parameter σ^b.

The calibration of the historical U.S. monetary policy reaction function is close to the coefficient estimates reported for the Federal Reserve Board's SIGMA model (Erceg et al., 2006) and the IMF's Global Projection Model (Carabenciov et al., 2013). The coefficients are $m_i = 0.7$, $m_\pi = 2.0$ and $m_{ygr} = 0.25$.[15] The calibration of the historical U.S. macroprudential reaction function assumes $\gamma_t = \overline{\gamma}$, given that CCCBs are a new feature of the Basel-III regime.

[15] Starting in 2008Q4 policy rates hit the zero lower bound. However, as argued by Lombardi and Zhu (2014), the overall monetary policy stance, taking into account various unconventional measures, was far more accommodative than indicated by the policy rate alone. Because the pre-2008Q4 monetary policy stance computed by Lombardi and Zhu (2014) closely tracked the evolution of the actual policy rate, this supports the view that, in a

The autocorrelation coefficients and standard deviations associated with the model's shocks are shown in Table 1b. The shock processes are calibrated to approximately reproduce the standard deviations, autocorrelations and cross-correlations of U.S. macroeconomic variables obtained from the FRED database for the period 1990Q1–2010Q2. Specifically, we consider the standard deviations of the growth rates of real GDP, real consumption, real investment and real government spending, the rate of inflation of the GDP deflator, the risk-free interest rate represented by the 3-month treasury bill rate, the risky spread represented by the difference between the BAA corporate interest rate and the 3-month treasury bill rate, and the growth rate of corporate net worth represented by non-financial corporate net worth. The magnitudes corresponding to corporate net worth and to risky spreads in the model are n_t^k and $i_{r,t} - i_t$, respectively. Any volatility in observed inflation π_t^{obs} that is not accounted for by the model's shock processes is assumed to be due to i.i.d. measurement errors, $\pi_t^{obs} = \pi_t S_t^m$, with $\ln(S_t^m) = \varepsilon_t^m$. We find that the monetary policy shock S_t^i does not contribute to matching the moments of the data, and, with one exception, we will therefore ignore this shock in the subsequent analysis.

Tables 2a and 2b show moments of the data and the model, while Table 3 shows an asymptotic variance decomposition. Despite the deliberate simplicity of our model, it matches several key moments of the data. Where it falls short is in the correlation of consumption growth and investment growth, which is negative in the model but positive in the data. Other problems, such as the weak correlation of consumption growth with output growth, are associated with the same underlying issue.

Three model simplifications are responsible for this. First, the assumption of flexible nominal wages implies that real wages drop strongly following a contractionary shock to investment and (with a short lag) to borrower riskiness, which limits the drop in labor demand and thus in output, thereby allowing consumption to rise. Second, the absence of an open economy dimension makes the mutual crowding-out effects of investment and consumption shocks much stronger, because a contractionary shock cannot be accommodated through a drop in imports. Third, the absence of a lending channel between banks and households implies that negative shocks to bank net worth only depress investment lending but not consumption lending, while in practice both of these tend to happen simultaneously.

In our view, given the strong correlation of corporate and household lending in U.S. data, especially during and after the most recent financial crisis, this third reason is by far the most important one. But that makes this a shortcoming that cannot be satisfactorily addressed through the introduction of additional shocks, or of correlated shocks,[16] but rather requires the introduction of additional structure whereby banks also lend to consumers, so that their *responses* to shocks are correlated across corporate and household lending. This requires a significantly more complex model, and thus there is a trade-off between simplicity and comprehensive empirical success. We have chosen simplicity, and leave the exploration of models with multiple types of lending to future work.

Another notable feature is that the model overpredicts the standard error of stock market growth, but underpredicts its autocorrelation, in line with many other models in this class. On the other hand, the volatility and autocorrelation of risky spreads are very close to that in the data. Both of these variables are mainly explained by borrower riskiness shocks, which are key for our welfare analysis.

Borrower riskiness shocks account for an 18% share in the volatility of GDP. Christiano et al. (2014)[17] find substantially higher shares, approaching 50%, for these shocks. Applied to our model, this would imply substantially larger welfare effects of macroprudential policies than what is reported below.

2.9. Welfare

Expected welfare is given by

$$\mathcal{W}_t = u_t + \beta E_t \mathcal{W}_{t+1}, \tag{36}$$

where u_t is the period utility of a representative household at time t. We define the Lucas (1987) compensating consumption variation $\eta < 0$ (in percent) of a specific combination of monetary and macroprudential rule coefficients as the percentage change in average consumption that households who experience the best possible combination of coefficients, with associated welfare $E\mathcal{W}^{opt}$, would be willing to tolerate in order to remain indifferent between their expectation of welfare under that best possible combination and the expectation of welfare $E\mathcal{W}^{rule}$ under the specific combination of monetary and macroprudential rule coefficients. The first step is to evaluate welfare under both assumptions relative to steady state welfare $E\mathcal{W}^{ss}$.

We thereby obtain η^{rule} and η^{opt}, where the formula for η^{rule} is

$$\eta^{rule} = 100\left(1 - \exp\left(\frac{\left(E\mathcal{W}^{rule} - E\mathcal{W}^{ss}\right)(1-\beta)}{\left(1 - \frac{v}{x}\right)}\right)\right) > 0, \tag{37}$$

(*footnote continued*)
simple model that does not feature unconventional monetary policy, using the pre-crisis policy rate specification as representing monetary policy throughout should be acceptable.

[16] See the IMF Working Paper version of this paper, Benes and Kumhof (2011).

[17] See also Jermann and Quadrini (2012).

Table 1b
Shock processes.

Shock process	Autocorrelation coefficients		Standard errors	
	Parameter	**Value**	**Parameter**	**Value**
Borrower riskiness shock	ρ_{σ^k}	0.87	$std(\varepsilon^{\sigma^k})$	0.110
Investment demand shock	ρ_{S^I}	0.59	$std(\varepsilon^{S^I})$	0.045
Consumption demand shock	ρ_{S^c}	0.54	$std(\varepsilon^{S^c})$	0.015
Government spending shock	ρ_{S^g}	0.95	$std(\varepsilon^{S^g})$	0.007
Technology shock	ρ_{S^a}	0.925	$std(\varepsilon^{S^a})$	0.024

Table 2a
Standard deviations and autocorrelations.

Observed variable	Standard deviations		Autocorrelations	
	Data	**Model**	**Data**	**Model**
GDP growth	2.64	2.53	0.48	0.46
Consumption growth	2.26	2.95	0.51	0.55
Investment growth	13.31	13.92	0.46	0.52
Government spending growth	2.82	2.84	−0.04	−0.03
Inflation	0.90	0.90	0.56	0.23
Policy rate	1.96	2.10	0.93	0.94
Net worth growth	10.04	15.41	0.49	−0.09
Risky spreads	1.65	1.70	0.93	0.82

Table 2b
Cross-correlations.

Observed variable pairs	Cross-correlations	
	Data	**Model**
Consumption, investment	0.42	−0.43
GDP, consumption	0.73	0.28
GDP, investment	0.81	0.73
GDP, government spending	0.06	0.15
GDP, inflation	−0.06	−0.21
GDP, policy rate	0.07	−0.14
GDP, net worth	0.40	−0.04
GDP, risky spreads	−0.20	−0.25

Table 3
Variance decomposition.

	S_t^a	S_t^c	S_t^I	S_t^g	σ_t^k	S_t^m
Variance decomposition (in %)						
GDP growth	38	12	30	2	18	0
Consumption growth	39	31	6	1	23	0
Investment growth	3	0	45	0	52	0
Government spending growth	0	0	0	100	0	0
Inflation	23	0	2	0	4	71
Policy rate	23	5	21	0	51	0
Net worth growth	0	1	18	0	81	0
Risky spread	2	0	2	0	96	0

and similarly for η^{opt}. Finally, we obtain $\eta = \eta^{opt} - \eta^{rule}$. We use DYNARE++ to compute unconditional welfare and compensating consumption variations, based on a second-order approximation to the welfare and policy functions of the model. We perform a multi-dimensional grid search over all monetary and macroprudential rule coefficients.

3. Results

3.1. Optimal coefficient combination

To obtain a baseline for both impulse responses and welfare comparisons, we first determine the joint overall welfare optimum, across all coefficients of the rules (32) and (33), by way of grid searches. We find that the optimal smoothing coefficient for the macroprudential rule, p_γ, is always very close to zero, and we therefore simplify the further analysis by setting $p_\gamma = 0$. We also find that introducing a loan gap or a loan-to-output gap into the monetary rule does not have welfare benefits once all remaining coefficients are set at their overall optimum values, and we therefore set $m_\ell = m_d = 0$. A monetary policy response to the output gap yielded slightly better welfare results than a response to output growth, and we therefore set $m_{ygr} = 0$. This leaves the monetary coefficients m_π, m_i and m_y to be optimized jointly with one of the macroprudential rule coefficients. We do so by way of four-dimensional grid-searches. In doing so we limit the search over inflation feedback coefficients to a plausible range of $m_\pi \in [1.5, 3.0]$.[18]

We find that when macroprudential policy responds to the output gap, welfare gains are far smaller than when it responds to the loan gap or the loans-to-output gap. The reason is that the latter directly capture a key aspect of bank balance sheets, and in response adjust a tool that moves bank balance sheets in the desired direction, while output gaps are subject to many influences that often have little connection with the state of banks. For the same reason, loan gaps are slightly superior to loans-to-output gaps. We will therefore from now on concentrate only on the case of loan gaps. The overall optimal coefficient combination for that case is $m_i = 0$, $m_\pi = 3$, $m_y = 0.1$, and $p_\ell = 6.0$. Here we have restricted the macroprudential coefficient to be no larger than 6. The reason, as we will demonstrate, is that larger values would imply a standard deviation of the CCCB in excess of 3 percentage points of bank assets, while the Basel-III rules envisage an upper limit of 2.5 percentage points. The precise values of m_i and m_y do not have large effects on welfare outcomes. In our analysis of the effects of setting different values for m_π and p_ℓ we therefore hold m_i and m_y at their overall optimum values.

3.2. Impulse responses

Figs. 1–5 show impulse responses that illustrate the effects of different degrees of countercyclicality of the CCCB when the economy experiences contractionary shocks.[19] Specifically, in each case we present results for $p_\ell \in \{0, 3, 6\}$, while keeping the monetary rule coefficients at the optimal values $m_i = 0$, $m_\pi = 3$ and $m_y = 0.1$. All figures refer to capital investment funds as corporates. Also, MCAR refers to γ_t, while CAR refers to the actual capital adequacy ratio, $100\check{n}_t^b/\check{\ell}_t$.

Fig. 1 shows impulse responses for a one standard deviation shock to σ_t^k that increases borrower riskiness. With a CCCB the prudential authority temporarily lowers the MCAR in the face of a contractionary shock, by setting $p_\ell > 0$. We observe that this, relative to $p_\ell = 0$, significantly reduces the volatility of output, hours, consumption and investment, as well as reducing the required fluctuations in the policy interest rate.

The shock, as can be seen in the third row of the figure, impairs corporate asset values. The effect on net worth is twice as large as that on asset values because corporate leverage equals 100%. Corporate leverage for a one standard deviation shock increases by around 3 percentage points on impact, and corporate defaults increase by 1 percentage point, in other words they double. As a result banks, who in the period of the shock are locked into their old lending rates, suffer lending losses that reduce their CAR by more than 0.3 percentage points. In response, banks increase the interest rate spread. This increase has two components. The first, under a fixed capital buffer, is a roughly 25 basis points initial increase in the wholesale spread over the policy rate, as banks attempt to repair their balance sheet through higher earnings, and the second is a roughly 100 basis points initial increase in the retail spread over the wholesale rate as banks compensate for higher lending risk. Both of these spread increases, as well as the accompanying but more gradual reduction in lending volumes, serve to further reduce investment and output.[20] Monetary policy aggressively lowers the policy interest rate, which by arbitrage immediately reduces bank funding costs and thus, by (23), wholesale lending rates. When macroprudential policy is also aggressive, specifically with $p_\ell = 6$, macroprudential policy responds to the reduction in bank loans by reducing MCAR temporarily (but very persistently given the persistent effects of the shock). This reduces the need for banks to quickly rebuild their net worth, through higher interest earnings, in order to escape further penalties. As a result, the CAR can remain below its long-run value for a substantial period, with banks nevertheless running a reduced risk of penalties – see the subplot “Percent of Banks Violating MCAR”. The wholesale spread therefore rises by 15 basis points less on impact, and is also much lower in the medium term. This in turn has positive feedback effects on the corporate sector, by reducing borrower riskiness endogenously, which means that the interest rate spread of retail rates over wholesale rates also declines, albeit only slightly. From the responses of output, hours, consumption and investment it is clear, and we will show this below, that this policy has sizeable welfare payoffs.[21]

[18] Schmitt-Grohe and Uribe (2007) adopt a similar approach.

[19] Impulse response functions for expansionary shocks are symmetric.

[20] The reasons for the accompanying increase in consumption were discussed in Section 2.8, when commenting on the negative correlation between consumption and investment in the model.

[21] A reduction in borrower riskiness would have the opposite effect to Fig. 1, with expansionary effects on credit and real activity. In this case macroprudential policy would require banks to add to their capital buffer, thereby moderating the expansion.

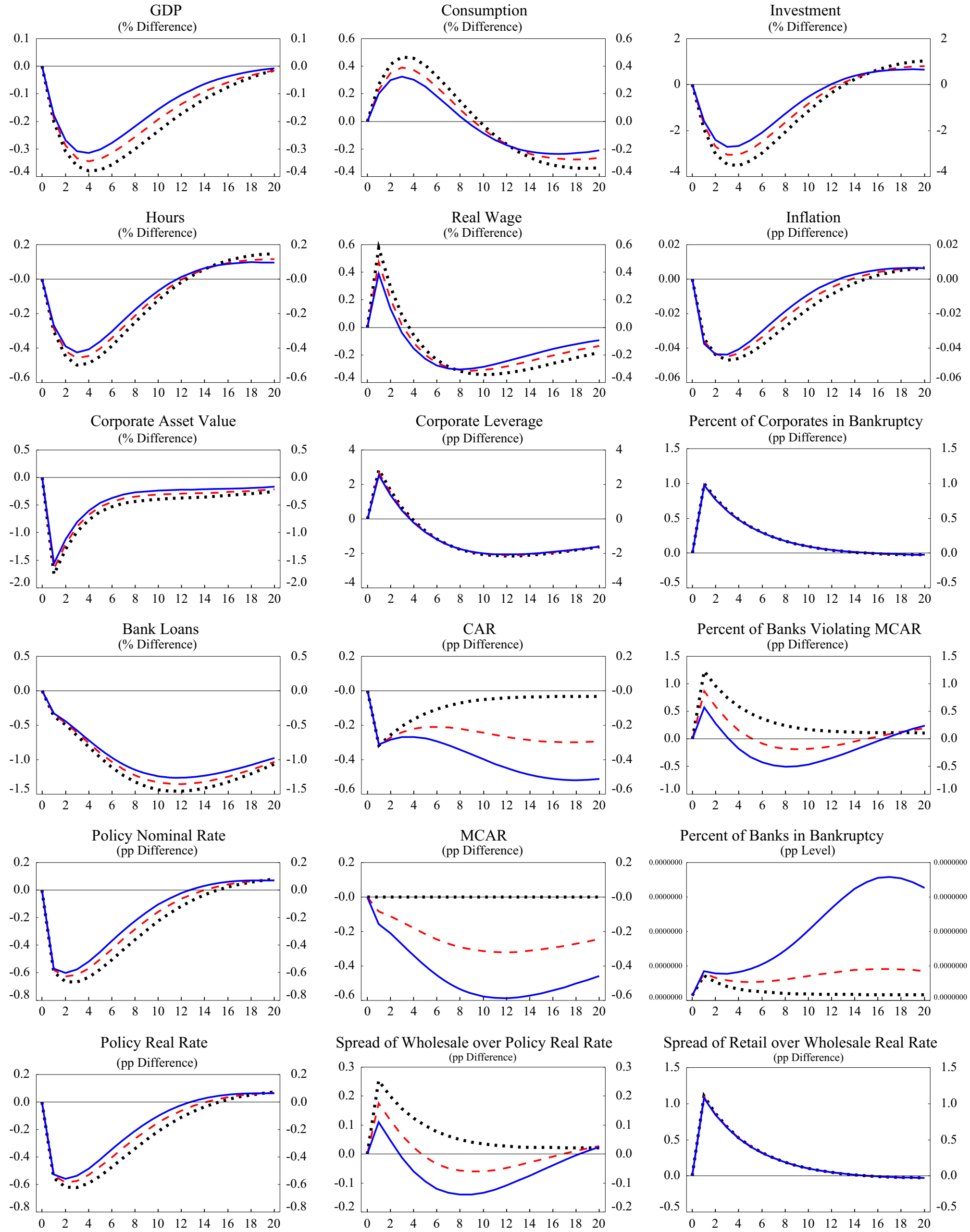

Fig. 1. Borrower riskiness shock (one standard deviation) (Feedback coefficients p_ℓ: …=0, - -=3, .=6).

Fig. 1 mainly illustrates how CCCBs can reduce the volatility of macroeconomic aggregates, with less attention paid to financial stability, in other words to the effect of CCCBs on the probability of banks going bankrupt. This is because banks in our model try to avoid dropping below the MCAR, thereby rendering the probability of banks losing all their capital negligible. This latter probability is shown in the subplot "Percent of Banks in Bankruptcy" – it is virtually zero. A CCCB does lead to a larger increase in the probability of bankruptcy than fixed capital requirements, but the numerical difference is insignificant. This therefore does not materially weaken the case for CCCBs. We have found that financial stability considerations only become significant for the desirability of CCCBs at substantially lower steady state MCAR than 8%.

Fig. 2 shows impulse responses for a one standard deviation contractionary investment demand shock. Lower investment reduces the financing requirements of the corporate sector and therefore leads to lower loan demand. Without a CCCB the CAR barely deviates from its target, while lending rates follow the reductions in the policy rate. But a more aggressive reduction of capital adequacy requirements allows banks to lower lending rates by more than policy rates. Lower real interest rates increase corporate net worth, which together with reduced borrowing costs boosts investment relative to

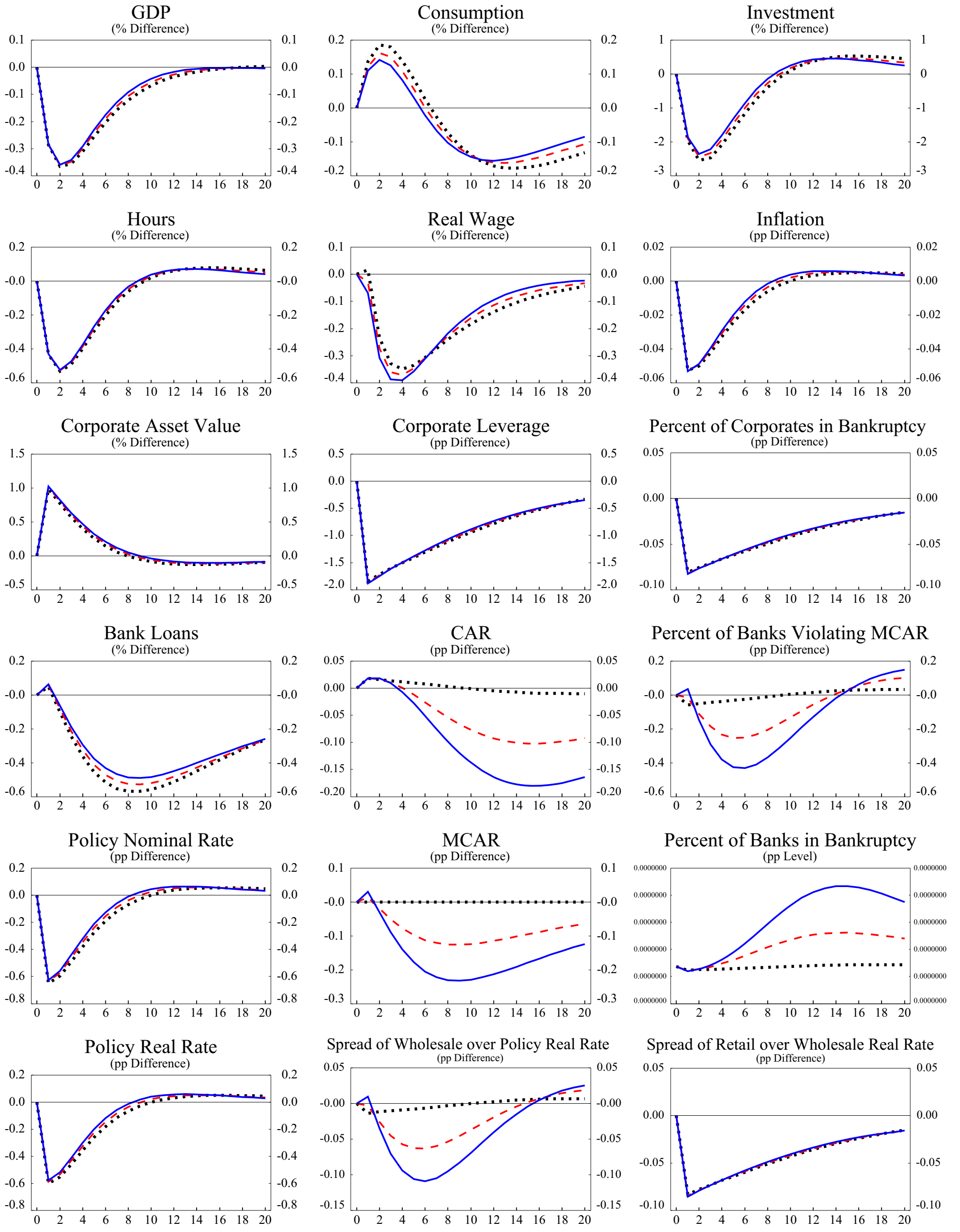

Fig. 2. Investment demand shock (one standard deviation) (feedback coefficients p_ℓ: …=0, - -=3, .=6).

the case of fixed MCAR. The resulting less volatile investment response has a positive effect on output and hours, and also helps to smooth consumption. But the effects of the CCCB in this case are much smaller than for borrower riskiness shocks.

Fig. 3 shows impulse responses for a one standard deviation contractionary consumption demand shock.[22] This shock implies a higher loan demand, because investment is crowded in by the drop in consumption, and also by lower real interest rates as monetary policy responds to lower overall demand. A CCCB therefore increases the contractionary effects of the shock by reducing the drop in lending rates. This has a negative effect on investment, which in turn leads to a larger overall contraction in output. In other words, for this shock the CCCB has procyclical effects, albeit small in magnitude. However,

[22] Results for a one standard deviation government consumption demand shock are similar but much smaller in size. Impulse responses are therefore omitted.

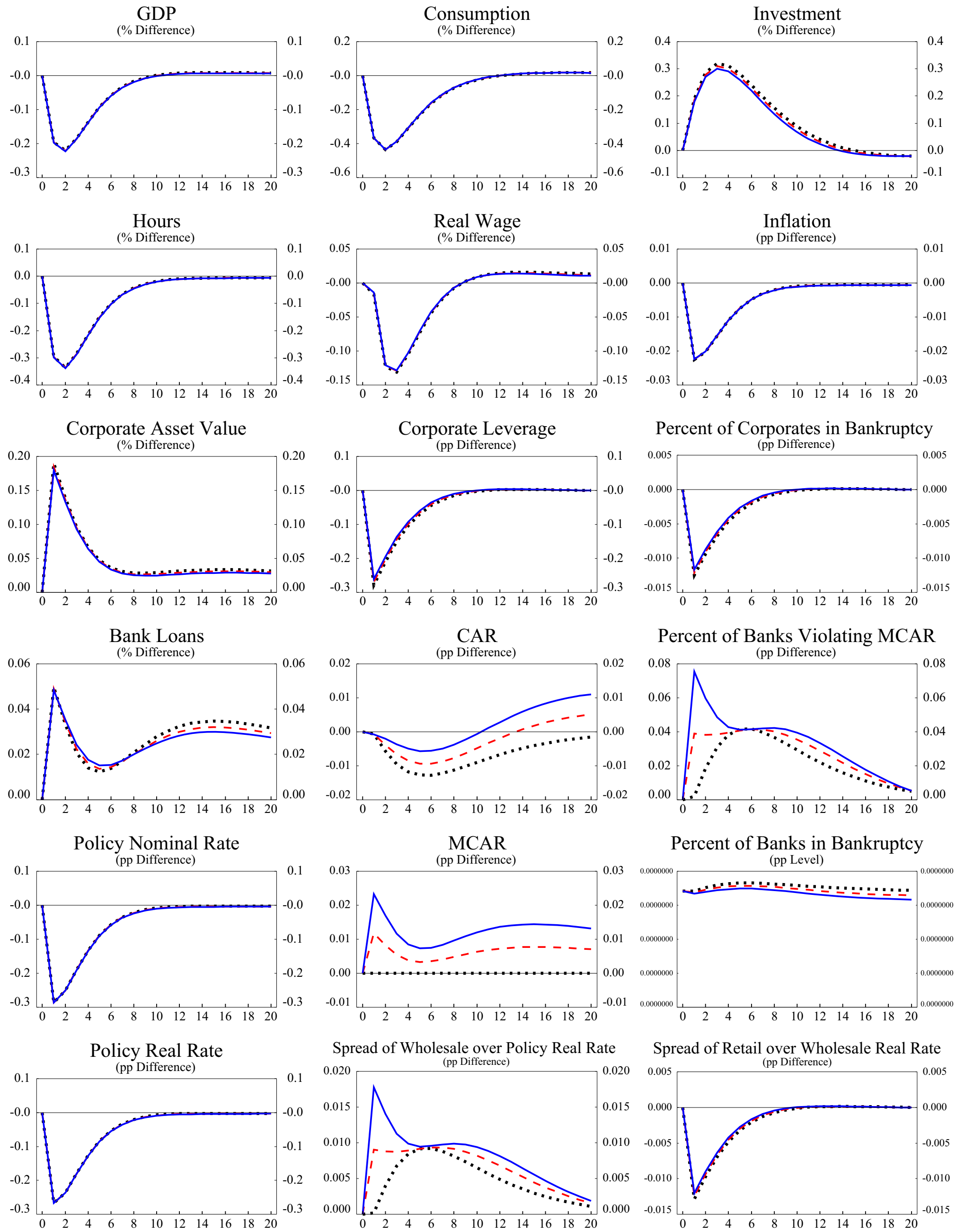

Fig. 3. Consumption demand shock (one standard deviation) (feedback coefficients p_ℓ: …=0, - -=3, .=6).

based on the discussion in Section 2.8, we conjecture that a CCCB would again have countercyclical effects if the model allowed for bank lending to consumers.

Fig. 4 shows impulse responses for a one standard deviation contractionary technology shock. Hours worked increase on impact, because aggregate demand falls much more slowly than the level of technology, due to real rigidities such as habit persistence and investment adjustment costs. A higher policy interest rate, in response to higher inflation, has a negative effect on corporate net worth, thereby increasing corporate leverage. Higher inflation also has a negative impact effect on the real value of loans. Loan demand remains persistently low thereafter, due to a combination of lower investment demand and higher policy interest rates. Absent a CCCB the effect on bank CAR is very small, but with a CCCB the ratio is lowered in response to lower loan demand, allowing banks to lower lending rates, thereby boosting investment. This reduces the drop in GDP, but it increases the volatility of both hours (by creating additional demand) and consumption (by crowding-out), and therefore reduces welfare.

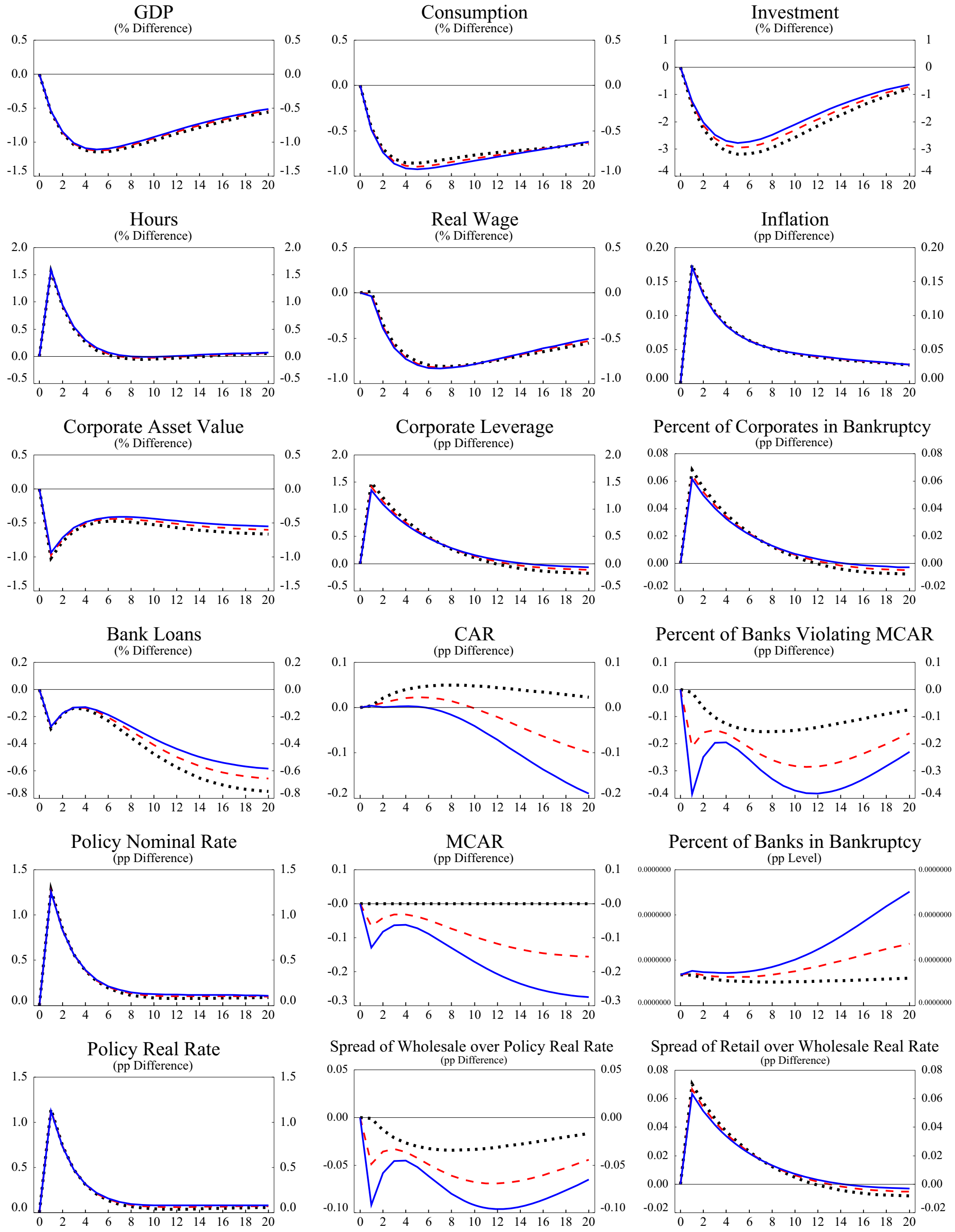

Fig. 4. Technology shock (one standard deviation) (feedback coefficients p_ℓ: …=0, - -=3, .=6).

While we find that monetary policy shocks do not contribute to matching the moments of the data, this finding is not universal, see e.g. Quint and Rabanal (2014). Fig. 5 therefore shows illustrative impulse responses for a monetary policy shock that increases the policy rate by one percentage point on impact, and that has an autocorrelation coefficient $\rho^i = 0.75$. This shock leads to an immediate contraction in consumption and investment, and to a drop in corporate asset values and net worth.[23] The subsequent recovery in corporate asset values is faster than the recovery in corporate net worth, so that capital investment funds need to borrow additional funds to finance their desired asset holdings. Under a CCCB this increase in bank lending triggers a 17 basis points increase in the MCAR and an 11 basis points increase in the spread of the wholesale rate over the policy rate, while under a constant MCAR this spread barely moves. Because an increase in

[23] As in Maddaloni and Peydro (2013), looser monetary policy can therefore work against a possible credit crunch that may be triggered by bank capital or liquidity constraints, by increasing corporate asset values.

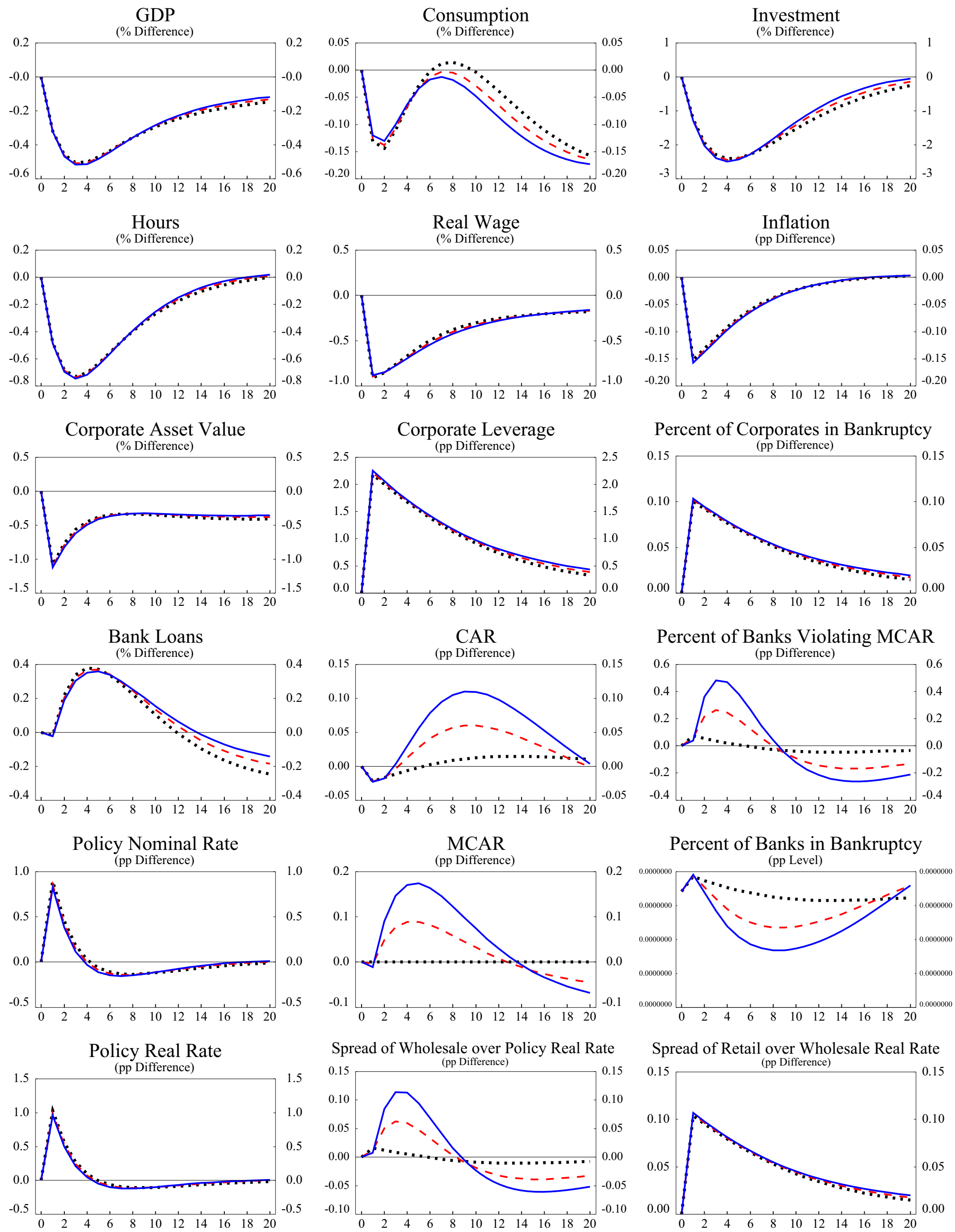

Fig. 5. Monetary policy shock (for illustration) (feedback coefficients p_ℓ: …=0, - -=3, .=6).

wholesale spreads further worsens corporate balance sheets, the retail lending spread also increases. As a result, output, investment and hours are more volatile. In our model, monetary policy shocks would therefore tend to reduce the benefits of CCCBs that respond to loan gaps. This also suggests that, at least during times of deliberate deviations from a systematic monetary policy rule, policy coordination between monetary and macroprudential authorities could have significant benefits.

Figs. 1–5 illustrate that a key question in analyzing the desirability of CCCBs is the nature of the shocks likely to hit an economy. When shocks are primarily to technology, to policy rates, or to components of aggregate demand that are not associated with a demand for bank loans, CCCBs may be procyclical and thus not desirable. But when a large portion of shocks is to components of aggregate demand that are associated with a demand for bank loans, or (much) more importantly to the financial system itself, through shocks that affect the creditworthiness of borrowers, CCCBs become very powerful, with large effects on macroeconomic volatility and, as we will show, welfare. In this context it is important to point out that our figures only show impulse responses for one standard deviation shocks, while the lognormal distribution

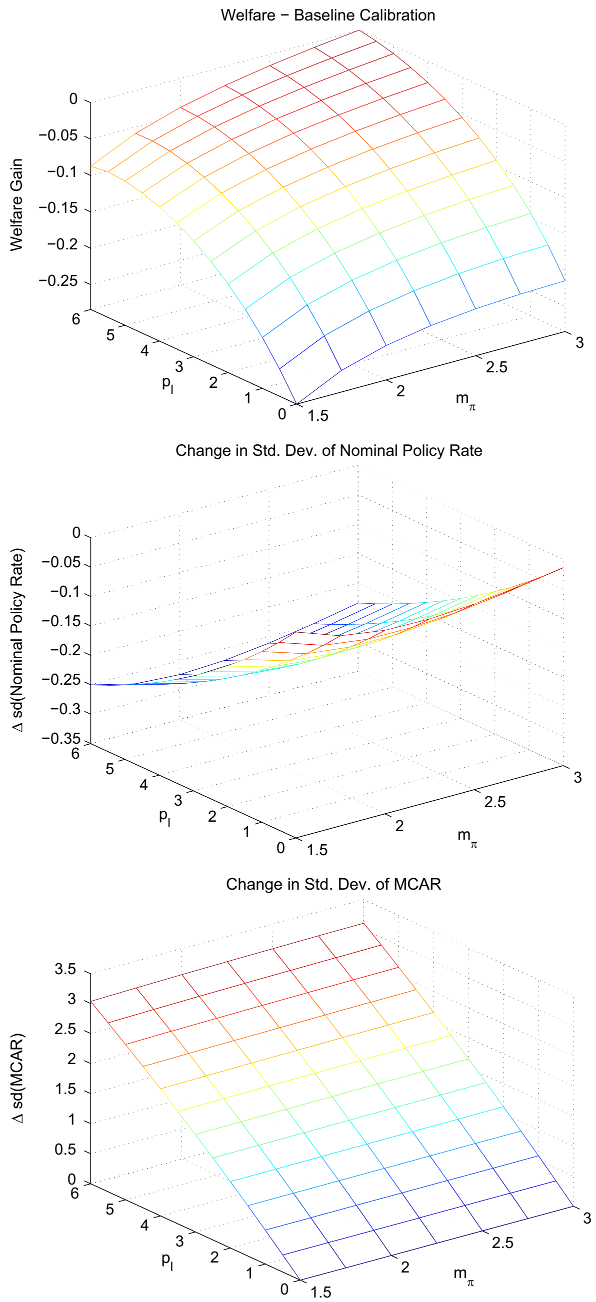

Fig. 6. Welfare and instrument volatility – all shocks.

functions which determine interest rate spreads in the capital investment fund and banking sectors imply disproportionately large effects on spreads in the case of the largest shocks. This means that rules which dampen the effects of such shocks have large welfare benefits.

3.3. Overall welfare and policy instrument volatility

Fig. 6 shows our main results for welfare and for policy instrument volatility. The top plot shows welfare outcomes as a function of the most important monetary and macroprudential rule coefficients m_π and p_ℓ, holding the coefficients m_i and m_y at their overall optimum values. The middle and bottom plots show the volatilities of the two policy instruments that are associated with the welfare results in the first plot. We have included the latter because, from a policymaker's perspective, policies need to not only be welfare-enhancing, but also practically feasible. This would not be the case if large welfare gains

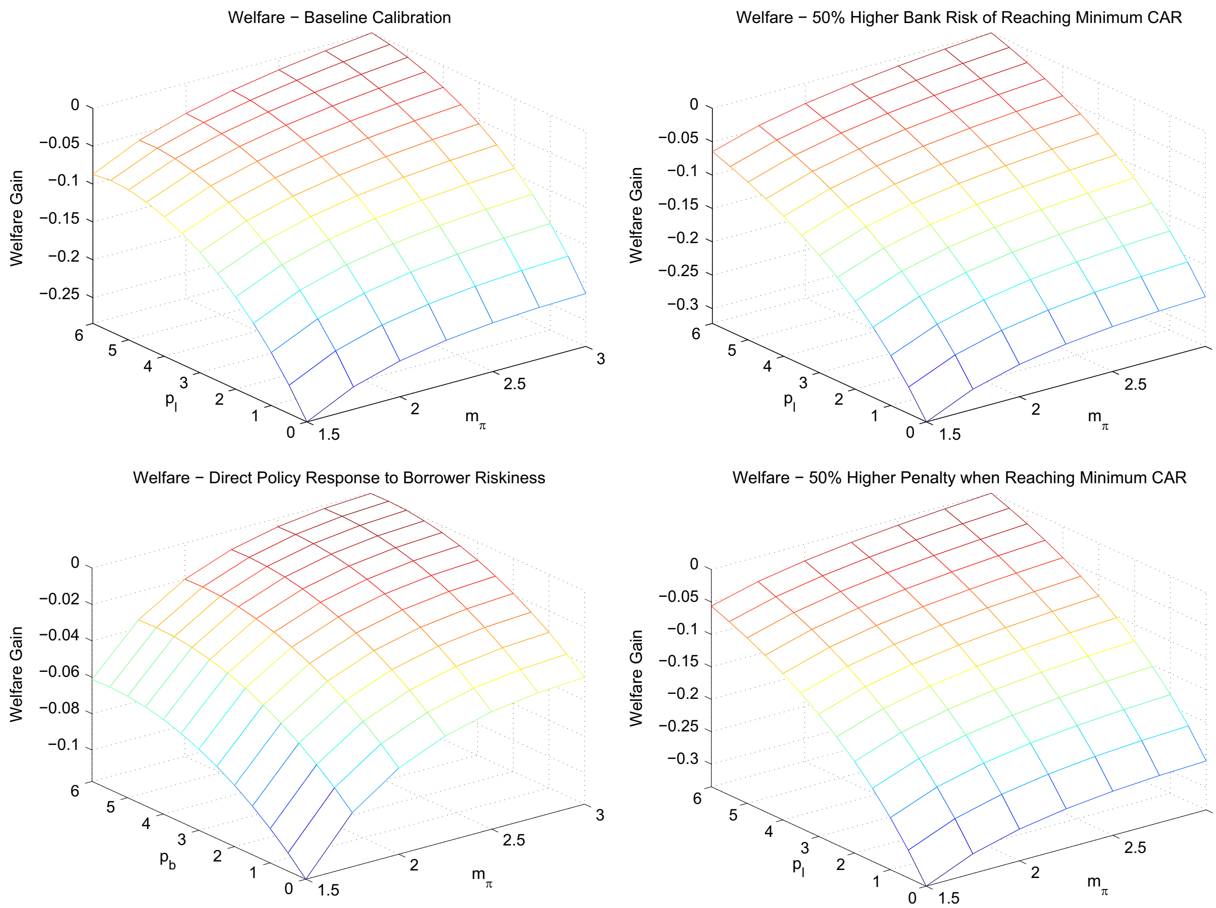

Fig. 7. Welfare – different model parameterizations.

were to require extremely volatile policy interest rates i_t, as argued in Schmitt-Grohe and Uribe (2007), or extremely large changes in MCAR γ_t, as discussed in Section 3.1. The reason is that such volatilities have costs that should ideally be part of the objective function, but it is not obvious how to incorporate this into the welfare computations. We therefore opt instead to present these measures side by side. Welfare losses are shown relative to the best policy rule available over the range that we consider, namely a macroprudential rule with $p_\ell = 6$ and a monetary rule with $m_\pi = 3$.[24]

An aggressive interest rate response to inflation improves welfare, and we find gains of an order of magnitude that are typical for, or perhaps a little larger than, what is commonly found in this literature. Specifically, when the remaining coefficients are at their overall optimum values, increasing m_π from 1.5 to 3.0 results in a welfare gain of around 0.09%. Macroprudential targeting of loan gaps on the other hand, specifically raising p_ℓ from 0 to 6, leads to a significantly larger welfare gain of around 0.21% of steady state consumption. Because the welfare surfaces are monotonic in both p_ℓ and m_π, there is no need for monetary and macroprudential authorities to coordinate the systematic components of their policies in order to improve welfare (see the discussion of Fig. 5 for the non-systematic components).

Coordination could however be important when policy is subject to limits in terms of acceptable policy instrument volatility. Here greater use of CCCBs reduces the volatility of policy interest rates, which may increase the scope to use policy rates more aggressively, while the converse is not true. The middle plot of Fig. 6 shows that more aggressive monetary policy increases the volatility of policy rates, while more aggressive CCCBs significantly (by more than 20 basis points) lower the volatility of nominal policy interest rates for any given inflation coefficient in the monetary rule.[25] The bottom plot of Fig. 6 shows that more aggressive CCCBs increase the volatility of MCAR, while a more aggressive monetary policy does not

[24] Because, over the range that we consider, the remaining coefficients are held at their overall optimum values, welfare gains approach their maximum as p_ℓ and m_π approach their overall optimum values.

[25] The result that capital adequacy requirements and policy rates are substitutes in terms of achieving macroeconomic stabilization objectives can also be found in Cecchetti and Kohler (2014).

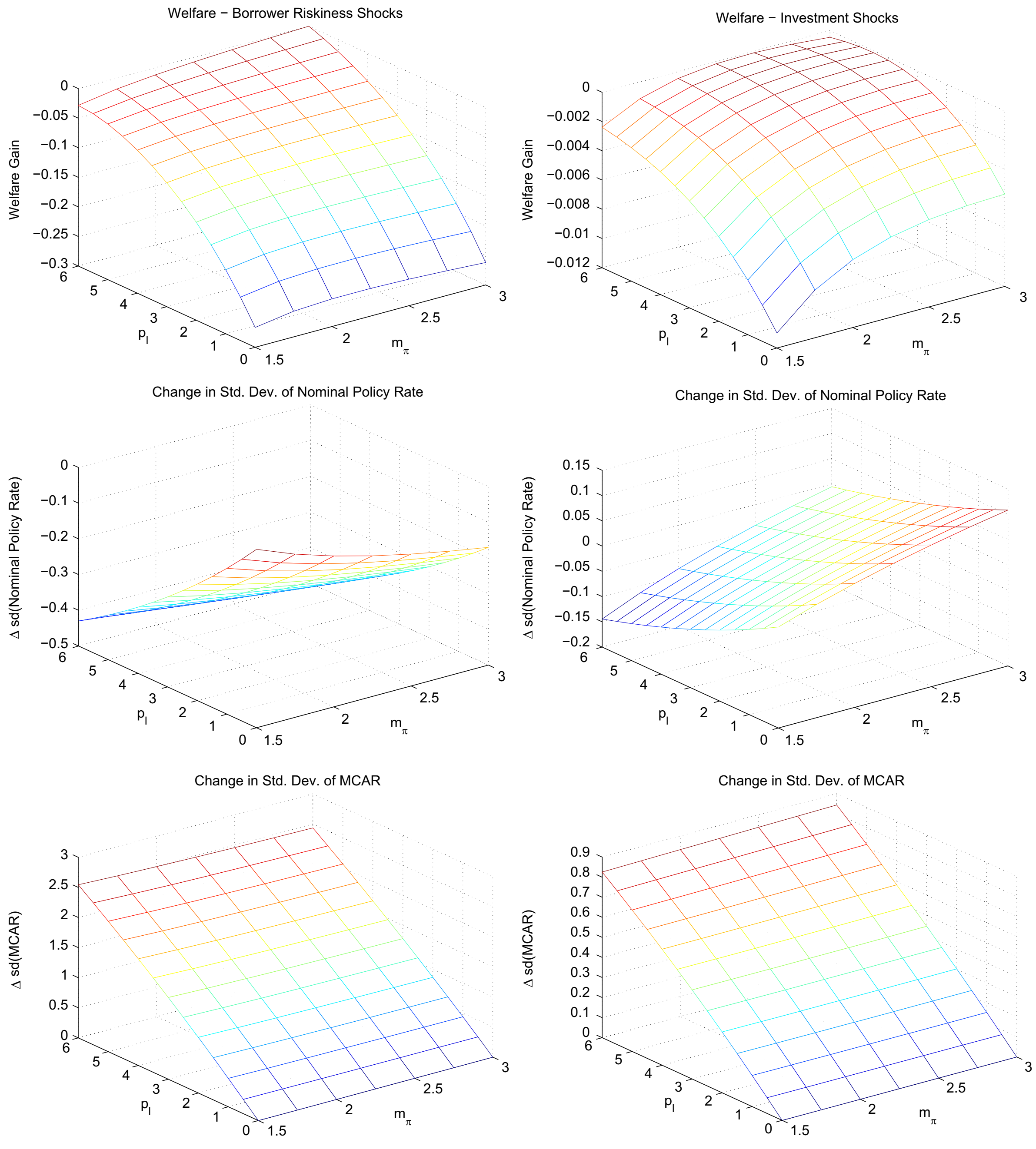

Fig. 8. Welfare and instrument volatility for borrower riskiness and investment shocks.

significantly reduce the volatility of MCAR. For quite aggressive macroprudential rules the volatility of MCAR becomes large, with a standard deviation at $p_\ell = 6$ that equals over 3 percentage points. Even though this may be at the limit, or beyond, of what policymakers and regulators would consider acceptable, gains at somewhat less aggressive macroprudential rules are still very large.

Fig. 7 shows how welfare gains change when we change aspects of the banking and regulatory technology. The top left panel shows the baseline from Fig. 6. The top right panel shows the consequences of banks becoming riskier, in the sense that σ^b rises to the point where the steady state share of banks that drop below the MCAR in any given quarter equals 3% rather than 2%. We observe that the welfare difference between the worst and best rules shown increases from 0.28% to 0.32%. The reason is that when banks face a higher risk of having to pay penalties, they will raise lending rates more aggressively in response to negative borrower

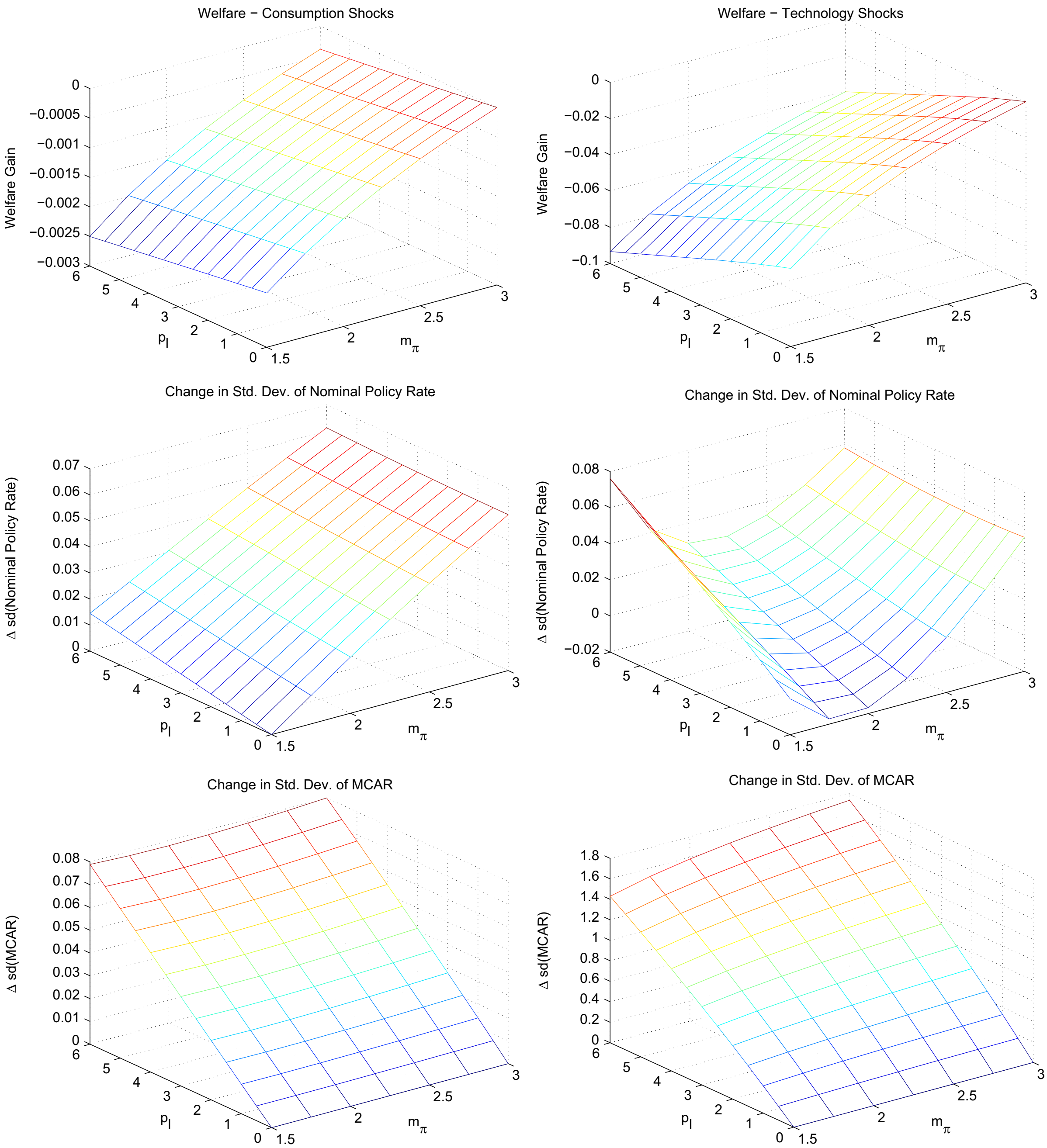

Fig. 9. Welfare and instrument volatility for consumption and technology shocks.

riskiness shocks, so that the relaxation of capital adequacy requirements becomes a more powerful tool. The bottom right panel shows the consequences of penalty costs equalling 0.5% instead of 0.33% of the value of loans. The welfare effects are similar to the previous case, with the welfare difference between the worst and best rules shown now increasing to 0.34%.

The bottom left panel of Fig. 7 shows the consequences of a different macroprudential rule. Fig. 6 showed that while the welfare gains of aggressive macroprudential rules are large, the associated volatility of MCAR can also become quite large. This however is due in large part to the fact, illustrated in more detail in the following subsection, that investment and technology shocks generate a significant part of the volatility of MCAR. The question therefore arises whether a direct response of macroprudential policy to borrower riskiness shocks alone, which would eliminate volatility of MCAR due to other shocks, could produce equally large welfare gains. The macroprudential rule that we consider for this case is[26]

$$\gamma_t = \overline{\gamma} - p_b \frac{\ln\left(\sigma_t^k / \overline{\sigma}^k\right)}{100}. \tag{38}$$

Fig. 7 shows that this rule produces much smaller welfare differences between the worst and best rules, with a maximum of 0.12% around $m_\pi = 3$ and $p_b = 6$, and with welfare in fact declining (not shown) just beyond $p_b = 6$. The reason is that the shock to borrower riskiness itself dies out comparatively quickly, while its effects on corporate and bank balance sheets are much more long-lived. Policy should optimally focus on minimizing the persistent effects of impaired balance sheets, through higher lending rates, on the rest of the economy, and a policy response to loans accomplishes that objective much better than rule (38).

3.4. Contributions of individual shocks

Figs. 8 and 9 decompose the welfare and volatility results into the contributions of individual shocks. The main result is that almost all of the welfare gains of an aggressively countercyclical macroprudential policy arise under borrower riskiness shocks, with much smaller gains under investment shocks, and small losses under technology and consumption shocks. The welfare gains from increasing the inflation feedback coefficient m_π are significantly smaller but always positive. The volatility of policy interest rates is reduced by CCCBs for those shocks for which that policy increases welfare. The volatility of MCAR of course increases with a more aggressive CCCB for all shocks. The largest share of that increase is again accounted for by borrower riskiness shocks, but in this case technology and investment shocks also play an important role.

4. Conclusions

We have presented a modeling framework that allows us to study an important element of the new Basel-III regulatory regime for banks, countercyclical capital buffers (CCCBs). In our theoretical model bank lending is risky because banks commit to their lending rates before they know the final performance of the underlying investment projects. Therefore banks can make loan losses that reduce their net worth. When they face regulatory penalties for maintaining insufficient net worth, they respond to the possibility of such losses by maintaining a capital conservation buffer, and to actual losses by increasing their earnings through higher lending rates. The latter further aggravates the negative effects of loan losses on the aggregate economy. CCCBs that build additional capital buffers during times of economic expansion, and release them during times of stress, can therefore improve macroeconomic performance, and if the long-run target capital adequacy ratio is sufficiently high this has negligible effects on financial stability.

We find that CCCBs can have sizeable effects on macroeconomic volatility and welfare when a significant share of the shocks hitting the economy are shocks to the creditworthiness of corporate borrowers. Both our paper and the recent literature have found such shocks to be empirically important, so that this result is of considerable practical relevance. In response to shocks that increase (reduce) borrower riskiness, CCCBs temporarily reduce (increase) capital requirements. During downturns this allows banks to rebuild their net worth more gradually, and therefore to limit the increase in loan interest rates that they charge to already distressed borrowers. The resulting reductions in the volatilities of output, investment, hours and consumption are sizeable. Furthermore, CCCBs reduce the required volatility of policy interest rates.

Appendix A. Supplementary data

Supplementary data associated with this paper can be found in the online version at http://dx.doi.org/10.1016/j.jedc.2015.06.005.

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[26] This analysis is done purely as a thought experiment that helps us to understand the nature of optimal prudential rules. It is hard to think how, in practice, a usable empirical counterpart of σ_t^k could be identified.

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