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The Effect of the Countercyclical Capital Buffer on the Stability of the Housing Market

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Abstract

After the great turmoil of the latest financial crisis, the criticism of the regulatory frameworks became increasingly stronger. The rules that banks needed to comply with are presumed to be procyclical and unable to prevent and mitigate the extent of strong financial and economic cycles. As a result, Basel III introduced a set of macroprudential tools to overcome these regulatory shortfalls. One tool that strives to counteract the issue of procyclicality is the countercyclical capital buffer (*CCyB*). This paper introduces a heterogeneous agent-based model that investigates the implication of the new regulatory measure. We develop a housing and a financial market where economic agents trade residential property that is financed by financial institutions. To examine the macroeconomic performance of the *CCyB*, we evaluate the dynamics of key stability indicators of the housing and the financial market under four different market conditions: in an undisturbed market and in times of three different structural shocks. Computational experiments reveal that the *CCyB* is effective in stabilizing the housing and the financial market in all market settings. The new macroprudential tool helps to mitigate economic fluctuations and to stabilize market conditions, especially in the aftermath of a crisis. It is not able to prevent any of the crises tested. However, the extent of the stabilizing effect varies according to market conditions. In the shock scenarios, the *CCyB* performs better in dampening market fluctuations and increasing banking soundness than in the base scenario.

Keywords Real estate finance · Housing market stability · Basel III · Financial regulation · Countercyclical capital buffer · Agent-based model

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Introduction

Financial accelerator theories have long been indicating the close interconnectedness between financial and real markets (Bernanke & Gertler, 1995; Bernanke et al., 1999; Hammersland & Jacobsen, 2008; Kiyotaki & Moore, 1997). Though, the mutual effects of the finance sector and the real economy as well as the impact of occurrences on the financial market on adjacent economic sectors have been overlooked in regulatory frameworks. The latest financial crisis and its aftermath triggered a large debate among policymakers and academics about banking regulation. The major contribution of the banking sector to the Great Recession led to the strong agreement that current frameworks were not sufficient. Especially, the microprudential focus was criticized. Instead of only supervising the soundness of individual institutions, the emphasis on interdisciplinary regulation arose and the design and the implementation of macroprudential policies drew attention.

As a consequence, banking regulation authorities passed the Basel III Accords which aim at strengthening the regulation, supervision, and risk management of banks by introducing a diverse set of macroprudential measures (BCBS, 2011). They are intended to enhance the stability of the financial sector and avoid destabilization of the economy by limiting the build-up of systemic risk (IMF, 2011). One dedicated tool of the set of macroprudential policies is the countercyclical capital buffer (*CCyB*). It is designed to mitigate the procyclicality of previous regulatory requirements and alleviate the magnitude of the financial accelerator. It extends the established capital adequacy requirements (*CAR*) by Basel II and allows national authorities to require an additional capital ratio in times of excessive credit growth (BCBS, 2019b). This build-up buffer shall protect financial institutions against future potential losses. In recessional times, it can be released to ensure sufficient credit supply. The possibility of adjusting *CAR* in a countercyclical manner gives the regulator a discretionary power so that the *CCyB* may act as a stabilizer, leaning against the financial cycle. By now, however, the contribution of the *CCyB* to the resilience of the banking sector remains unclear. Higher *CAR* might alter the quality of borrowers, lessen bank lending and relocate the business activities of financial intermediaries.

The aim of this paper is to assess the effectiveness of the *CCyB* in mitigating fluctuations in mortgage loans and the extent of booms and busts in house prices. Existing literature that investigates the new macroprudential tool often examines its design (Lambertini et al., 2013; Liu & Molise, 2021; Lozej et al., 2018; Tölö et al., 2018). Some studies assess its impact on producing economies (Cincotti et al., 2012; Popoyan et al., 2020). However, although the housing market is one of the most important markets of an economy and it is considered to be the main catalyst of the latest Great Recession, to the best of our knowledge, no study exists that evaluates the *CCyBs* impact on the housing and the mortgage market and its effectiveness in reaching regulatory goals. The empirical work of Basten (2020) reveals that the introduction of a *CCyB* changes the composition of mortgage supply. Mortgage-specialized banks slow down their mortgage growth and rebuild capital cushions while market-wide mortgage growth does not slow down significantly. These results are based on Swiss market conditions and exemplify possible impacts. Insights about the *CCyBs* general effects, especially in times of abnormal market conditions do not yet exist.

We introduce a macroeconomic agent-based model of a real estate market in which housing is financed by financial intermediaries to evaluate the effectiveness of the *CCyB* as a macroprudential tool to mitigate fluctuations in house prices and credit and at the same time, stabilize the financial sector.

The interaction between the economic agents creates endogenous housing market cycles. The resulting market conditions resemble realistic market structures that allow assessing the effect of introducing a *CCyB* on the real estate market and the solidity of the banking sector. Furthermore, we introduce different external shocks to test the effectiveness of the *CCyB* of being a preventive and stabilizing tool during times of exceptional market occurrences.

Conducting computational experiments, we show that the newly introduced macroprudential tool succeeds in mitigating housing market cycles, excessive credit growth, and increasing the resilience of the banking sector in all of the investigated scenarios. If national authorities oblige banks to extend their equity capital in times of excessively rising house prices, the procyclicality of banks' mortgage lending practices is reduced, sharp price booms are prevented and deep downturns are flattened. The stability-increasing effects coincide, however, with a decreasing rate of homeownership, transactions and constructions in the housing market. In the aftermath of a crisis, the *CCyB* helps to create stabilized house price oscillations. However, if a market is hit by a shock, the macroprudential measure is not able to prevent the market from a recession. The results further indicate that the extent of the shock and the timing of the installation of an additional *CAR* requirement is decisive for achieving regulatory goals.

This study contributes to existing research as it evaluates the impact of the *CCyB* on the housing and mortgage lending market. The huge importance of the real estate market was evidenced during the latest financial crisis where the great potential of the real estate market to destabilize the whole economy was expounded. By elaborating on whether the new regulatory macroprudential tool serves its purpose, the insights of this study have important implications for the current policy discussion in different EU legislative frameworks and other global countries about introducing the *CCyB* based on an excessive increase in house prices and mortgage volume in the previous years.

The rest of the paper is organized as follows. In Section 2, we introduce the model structure and provide a detailed description of the agents' characteristics and their behavioral features. Section 3 presents the results of the computational experiments in the baseline scenario. Section 4 introduces three different shocks and compares the outcomes of the tested scenarios. Section 5 concludes.

Model Structure

Our model is a macroeconomic real estate business-cycle model featuring a housing market and a banking sector. The model builds on Braun et al. (2022) and incorporates banks' limitations in business practices introduced by regulatory micro- and macroprudential *CAR* that aim at strengthening the financial market and avoiding macroeconomic destabilization.

The model is populated by three types of heterogeneous agents: buyers, sellers, and stylized conventional banks. Buyers and sellers constitute the housing market. Potential buyers demand housing units according to their individual preferences for housing investment and consumption. Sellers form expectations about future market developments and decide whether to provide housing supply. Banks either finance residential property or invest in an alternative asset portfolio. They need to comply with the *CAR* of Basel III and are thus constrained in business activities.

The model considers individual penchants of agents and creates a generally applicable, globally transferrable market setting. It incorporates the heterogeneity inherent in the real estate market, allowing agents to align their actions to individual expectations about future market conditions. As cyclical patterns of house prices and mortgages differ according to external circumstances, we introduce three types of external shocks to test the effectiveness of the macroprudential *CCyB* under different economic circumstances. The method of agent-based modeling allows for assessing agents' interactions, market conditions, and the resilience of market sectors in these different scenarios.

The Housing Market

The housing market consists of buyers and sellers, while sellers can either be households or residential construction firms. All of the agents are characterized by individual characteristics and considerations of market conditions. They trade housing units, thus forming endogenous market conditions. The housing market is competitive. No real estate seller has market power and not every potential buyer who aims at homeownership may buy one.

Buyers

Potential real estate buyers enter the housing market at the beginning of each period, demanding self-occupied residential property. They derive utility from owning a housing unit h and consuming any other consumption good c. This relationship is stated by a Cobb–Douglas utility function in the form of $U_b = c^\alpha * h^\beta$where c^α states the utility buyer b derives from consuming any consumption goods except housing investment and h^β states the utility he derives from being a homeowner. Buyers are heterogeneous in terms of their preferences with $\alpha \sim N(0, 1)$ and $\alpha + \beta = 1$. They are assumed to be households that earn a periodical income Y_t that is fully spent in each period. The herewith related budget constraint is given by $Y_t = P_{c,t}c + P_{h,t}h$.

Furthermore, buyers are capitalized with a fixed amount of equity E that is derived from a uniform distribution on $E \sim U(0, 0.35)$.[1] Available equity is fully spent on buying residential property.

Potential buyers seek to maximize their utility. Following this maxim and solving a buyer's utility function for P_t while $h = 1$ using the method of Lagrange multipliers, we obtain the highest possible periodical expenditure b can afford for housing investment given its budget constraint. This can be stated to be the potential buyer's b reservation price:

$$P_{res,b,t} = \left(\frac{Y}{\left(\frac{\alpha}{\beta} + 1 \right)} \right) - \left(r(P_t - E \right). \tag{1}$$

The amount exceeding the buyer's equity is mortgage financed which bears interest cost r_t on the loan volume $(P_t - E)$ and a periodical redemption r_p.[2]

While the reservation price states the upper threshold a buyer is able to raise for buying a dwelling, he forms an expected market price, based on past market conditions and expectations about future market developments before stating a bid. The expected market price of a potential buyer b is:

$$P_{expected,b,t} = (1 + e) * (P_{t-1} + \Delta P_{t-1}), \tag{2}$$

where e designates a buyer's expectation about future market conditions while $e \sim U(-0.1, 0.1)$, P_{t-1} designates the price level of the previous market period, and ΔP_{t-1} the price change during the last period. Considering his budget constraint and individual market sentiments, a potential buyer only places a bid if $P_{expected,b,t} \leq P_{res,b,t}$. A household's demand for housing thus is:

$$Bid_b = min\left(P_{expected,b,t}, P_{res,b,t}\right). \tag{3}$$

Sellers

Real estate sellers state the housing supply in the real estate market. They are assumed to be households, too, who sell already established owner-occupied dwellings, or residential construction firms that build and sell new houses. At the beginning of each period, sellers evaluate current market conditions and form expectations about future price developments. Seller s only offers a dwelling for sale if this promises a higher profit than keeping it and selling it in subsequent periods, speculating for house price appreciations. Just as buyers, sellers differ in terms of their attitudes toward upcoming market conditions. The future price s expects follows this

[1] The equity distribution reflects the distribution of German households in the year 2021. Data is obtained from the German Federal Statistical Office.

[2] We assume a redemption period of 10. This leads to 10 payments on the principal and $r_p = 0.1$. Interest and redemption sum up to $r = r_t + r_p$.

of buyers which is $P_{expected,s,t} = (1+e) * \left(P_{t-1} + \Delta P_{t-1}\right)$,where e indicates the seller's belief of market changes and $e \sim U(-0.1, 0.1)$. Considering profits from future sales discounted to today compared to profits out of selling the dwelling in the prevailing period and investing freed-up liquidity in an alternative investment AI that bears interest at the risk-free interest rate r_f, a seller only places an offer if:[3]

$$P_{t-1} + \frac{(r_f AI)}{(1+r_f)} \geq \frac{(1+e) * \left(P_{t-1} + \Delta P_{t-1}\right)}{\left(1+r_f\right)}. \tag{4}$$

If (4) holds, s offers his house for sale at the last observable market price which is P_{t-1}. This determines the seller's reservation price which may differ from his ask price. Before stating his offer, he figures out whether a buyer or a seller market exists. For this purpose, he calculates $\varphi = \frac{(NB-NS)}{(NB+NS)}$where NB states the number of buyers and NS the number of sellers on the market. If $\varphi > 0$ and buyers exceed sellers, s adjusts the ask price upwards. If the opposite holds and $\varphi < 0$, the seller's ask price equals his reservation price which is P_{t-1}.

Buyers and sellers are restricted to buying/selling one unit of housing per period and leave the market if their purpose is served. Furthermore, a seller cannot be a buyer in the same period. Depending on market activities, it may happen that a house is not sold in t. This property remains on the market and is offered in t_{+1}. To increase the probability of sale, the seller lowers the price by a markdown ratio ς for which $0 < \varsigma < 1$ applies. The same holds for t_{+2} if the dwelling stays unsold in t_{+1} and applies for all subsequent periods until the house is sold. Considering all the circumstances and the herewith related decision criteria, a seller's ask price is:

$$P_{ask,s,n} = \begin{cases} \left(P_{t-1}(1+\varphi)\right)\varsigma^n for \varphi_t > 0 \\ P_{t-1}\varsigma^n for \varphi_t < 0 \end{cases}, \tag{5}$$

where n denotes the number of periods a dwelling is offered for sale. If a house is not sold for 30 periods, it is assumed to be depreciated and removed from the market.

Housing Price

The price index of houses and its development over time is the key measure for agents to assess current market conditions and form expectations about future developments. As economies are complex adaptive systems in which agents with deviating beliefs interact with each other, we deviate from classical approaches that determine the equilibrium price. Instead, we follow Filatova et al. (2007) and allow prices to be built by bilateral bidding.

Buyers and sellers are matched and a sale takes place if a buyer's bid equals or exceeds a seller's ask price. The matching process follows a first-price-sealed-bid auction in which bids are assigned to offers in descending order. If two bids are

[3] The interest of the alternative investment is paid out at the end of a period.

equal and thus are both assigned to the same offer, they are randomly matched. The transaction price of a single deal is the mean of the matched bid and offer.

The price index of houses for one period is calculated as the mean of all transactions that have taken place during this time:

$$p_{h,t} = \left(\frac{1}{N_{transactions},h} \right) \sum_{h=1}^{N} P_h, \tag{6}$$

where $N_{transactions}$ indicates the sum of conducted transactions in one period and P_h indicates the transaction price of the sold unit h.

Number of Properties

The number of properties available for sale on the market is determined by the sellers' evaluation of current and prospective market conditions. Both types of sellers, households[4] and residential construction firms, aim at profit maximization and align their offers accordingly. Those offers from sellers are either first-time sales, $N_{newsellings}$, or unsold dwellings from previous periods, $N_{leftover}$.

Construction firms assess various market condition indicators to decide whether to build new houses and if yes, how many. By computing φ_{t_2} they consider whether the market lacks or exceeds supply. This measure is extended by the number of buyers who did not succeed in acquiring property two periods ago,$N_{remainingbuyers,t-2}$. The price changes of previous periods are calculated by $\rho_{t-2} = \left(\frac{P_{t-2}+\Delta P_{t-2}}{P_{t-2}} \right)$. The number of houses for first-time occupations accordingly is[5]:

$$N_{constructions,t} = N_{remainingbuyers,t-2} * \varphi_{t-2} * \rho_{t-2}. \tag{7}$$

The construction period is assumed to last one period. Therefore, the information to decide on how many dwellings to build at the beginning of t_{-1} stems from t_{-2}. Following this approach, we adjust supply to prevailing market conditions and, at the same time, account for the delay in supply because of long construction periods. The ask price formation of residential construction firms follows this of sellers, stated in Eqs. (4) and (5).

The stock of houses available for sale in one period is the sum of the previous components:

$$N_{h,t} = N_{newsellings,t} + N_{leftover} + N_{constructions,t}. \tag{8}$$

The Financial Market

The financial market is populated by a set of banks. Each of them aims at profit maximization. Following their perceptions of market conditions and beliefs about

[4] In the following, the term, seller ' designates households while 'residential construction firms' means those agents who sell newly constructed houses for initial occupancy.

[5] For the number of constructions, $N_{constructions,t} \geq 0$ holds.

Table 1 Balance sheet structure of banks

Assets		Liabilities	
Cash (*C*)		Debt (*D*)	
Risky Assets		Equity *(E)*	
	Mortgages (*T*)		Free equity
	Alternative Investment (*AI*)		Regulatory equity for *T*
			Regulatory equity for *AI*

future price developments, they form individual investment strategies and decide how to allocate funds. The model setting offers three investment opportunities. Banks can either hold cash, grant mortgages to potential real estate buyers or invest capital in another risky asset which is supposed to be a diversified market portfolio of financial assets that represents any alternative investment opportunities of banks. Cash earns no interest and is supposed to be risk-free. Mortgages and the alternative investment portfolio *AI* generate returns but are associated with default or price risk. Conducting such risky business is constrained by Basel III regulations. If financial agents decide to either grant mortgages or invest in *AI*, they need to comply with the regulatory capital adequacy requirements (*CAR*), including a countercyclical capital buffer (*CCyB*).

In addition to the individual market assumptions and investment strategies, each bank is characterized by distinct balance sheet positions. These are displayed in Table 1. The composition of balance sheets is initially calibrated on the German banking sector and can be seen as a reasonable proxy for any other countries. To extract any stationary balance sheet compositions, we use the average of the last ten years which is the period from 2012–2021. Conducting business and following their investment strategies, the balance sheet positions vary every period. At the end of each period, the respective balance sheet positions are recalculated.

Cash is used to buy *AI* and to comply with liquidity requirements introduced by Basel III. Bought shares decrease the cash position whereas sold shares increase it. The opposite effect is realized for the *AI*-Portfolio. An excess in cash is mainly held by risk-averse agents. The volume of mortgage loans expands if new mortgages are granted. Repayments and defaults make the mortgage portfolio shrink.[6] The equity position changes according to accrued gains and losses. Depending on the development of prices of the alternative investment portfolio, banks might face gains or losses. These as well as losses out of defaulted mortgages are directly translated into changes in equity. As banks have various funding opportunities, which

[6] The repayment period is assumed to be 10. A respective fraction of mortgages is repaid in every period. Mortgage default rates are obtained from the statistical data warehouse of the ECB from the periods 2015 –2021.

do not directly influence the impact of the *CCyB*, we forgo modeling those. Instead, the debt position is calculated as the difference between total assets and equity and develops passively. According to this recalculation process, it is assessed whether banks comply with or violate Basel III rules. The change in balance sheet positions is the result of individual agents' expectations and interactions. The financial market is competitive and no single institution has market power.

Regulatory Capital Adequacy Requirements including CCyB

As a response to the latest financial crisis, the Basel Committee on Banking Supervision (BCBS) introduced a new regulatory framework that tightens microprudential regulations on the banking sector and adds macroprudential requirements. The microprudential rules comprise the minimum risk-based capital adequacy requirements (*CAR*) that require banks to hold a minimum amount of equity. The revised framework sets higher quality standards for loss-absorbing capital than its predecessor and raises the level of the required core capital ratio. The minimum *CAR* are defined as the bank's Common Equity Tier 1 capital (*CET*1) relative to its total risk-weighted assets (*RWA*). The static minimum level of *CAR* the regulator requests is:

$$CAR = \frac{CET1}{RWA} = \frac{CET1}{\left(rw_T * T\right) + \left(rw_{AI} * AI\right)} \geq \overline{\epsilon} \text{ with } \overline{\epsilon} = 4.5\% \,. \tag{9}$$

where a bank's *RWA* represent its assets weighted each by their corresponding probability of default according to the guidelines of the BCBS (BCBS, 2019a).

The risky assets a bank can invest in this model are either mortgage loans or a market portfolio of financial assets. As we calibrate banks' balance sheets on BankFocus data from 2012 to 2021, we incorporate a distribution of *RWA* of real banks. According to the regulatory setup, cash is supposed to be risk-free. The risk weight of mortgages is determined according to the custom *LTV* of potential borrowers.[7] The market portfolio is supposed to be a diversified asset portfolio for which the BCBS risk weight of 100% is assigned (BCBS, 2017b).

The *CCyB* is one of the newly established macro-financial tools of the Basel III Accords that aims at augmenting overall financial stability and avoiding destabilization of the economy by mitigating credit booms and related procyclicality in the financial system (BCBS, 2017a). To lean against financial cycles, the regulator allows national authorities to impose further capital requirements on banks when excess aggregate credit growth is judged to be associated with a build-up of system-wide risk (BCBS, 2019b). This increase in capital ratios shall moderate upswings and build a cushion to render banks more resilient to potential losses. In adverse market periods, this buffer shall be released to counteract credit constraints when capital is scarcely available.

[7] The BCBS defines the *LTV* ratio as the loan amount divided by the value of the financed property (BCBS, 2017b). Following this definition, the *LTV* ratio of a borrower in this model is $LTV = \frac{(T-E)}{P_h}$. Table 11 in the appendix depicts the risk weights of the respective *LTV* ratios according to the BCBS.

By now, there is no clear specification by the regulator and no consensus in the literature on which variables to use to decide about imposing the *CCyB*. As the main objective of macroprudential policy is to protect the financial system from the risks associated with excessive credit growth without compromising macroeconomic stability, in our model, previous credit growth serves as a measure to detect economic up- and downswings. This follows the approach of Braun (2023). To set the *CCyB* accordingly, we calculate the *CCyB* as:

$$\kappa_t^m = \begin{cases} \kappa_{min} for \frac{\Delta M}{M} \leq 0 \\ \kappa_{max} * \frac{\Delta M}{\Theta M} for 0 < \frac{\Delta M}{M} < \Theta \\ \kappa_{max} for \frac{\Delta M}{M} \geq \Theta \end{cases}, \tag{10}$$

where $\frac{\Delta M}{M}$ indicates the percentage change of the aggregate loan portfolios of banks from the previous to the current period and Θ indicates the threshold of mortgage growth above which κ_t^m is set at its maximum.[8]

The *CCyB* varies between $0 \leq \kappa_t^m \leq 2.5\%$ of risk-weighted assets and complements the narrowed *CAR* stated in (9) (BCBS, 2019b). Accordingly, summed up *CAR* for one period, considering prevailing market conditions is $CAR = \frac{CET1}{(rw_T * M) + (rw_{AI} * AI)} \geq \overline{\epsilon_3} + \kappa_t^m$ where $4.5\% \leq \overline{\epsilon_3} + \kappa_t^m \leq 7.0\%$. Using this approach, we follow the request of the regulator to introduce a mechanism that encourages banks to build up and release capital buffers according to the economic conditions.

Mortgage Supply

The fundamental process of mortgage supply also builds on Braun et al. (2022) and Braun (2023). As banks are the economic agents that distribute funds to potential home buyers and originate mortgage loans, they play an indispensable and decisive role in market activities. Their decision about mortgage lending determines the possibility of acquiring residential property which transforms into the exercised demand for residential real estate. While potential house buyers and sellers create market interactions in the real estate market, banks inextricably link the housing and the financial market.

Banks are assumed to be risk-neutral agents that seek to maximize profit. Therefore, their decision about approving or rejecting loans primarily depends on the expected profit of mortgage lending in comparison to any other investment opportunities. Considering that potential buyers become borrowers when a loan is affirmed who embody an individual risk of default, banks only approve a mortgage if:

$$\left(qr_t + (1-q)r_d\right) - c_t \geq r_{AI}, \tag{11}$$

[8] For the simulations, we set $\Theta = 5\%$. This mimics the average long-time increase of mortgage loans in Germany (German Central Bank, 2019).

where q represents a potential borrower's non-default probability, r_t the mortgage interest rate, r_d the rate of return in case of default,[9] c_t the opportunity costs of lending that arise due to the capital requirements of Basel III, and r_{AI} the expected return of AI.

Solving (11) for r_t, we achieve a lender's indifference rate for loan granting which is the lowest mortgage interest he would accept as a function of an applicant's non-default probability.

$$r_t = r_d + \left(\frac{r_{AI} - r_d}{q} \right) - c_t. \tag{12}$$

The model is populated by a diverse set of heterogeneous financial agents which ensures that no single institution has market power and excess return on mortgage lending is eliminated by competition. Correspondingly, $r_t = r_{min}$.

In return for conducting risky business, the regulator imposes the prudential Basel III rules on banks which require them to comply with the CAR presented in "Regulatory Capital Adequacy Requirements including CCyB". These rules constrain business activities and cause opportunity costs out of forgone investments which are given by:

$$c_t = r_{wT} * \left(\frac{\varnothing r_t + \varnothing r_{AI}}{2} \right), \tag{13}$$

where r_{wT} indicates the custom mortgage's risk weight, $\varnothing r_t$ the average of past mortgage returns, and $\varnothing r_{AI}$ the average of past returns of AI.[10] The effective indifference return of a mortgage T is $r_{T,eff,m} = \left(r_d + \left(\frac{r_{AI}-r_d}{q} \right) \right) - \left(r_{wT} * \left(\frac{\varnothing r_t + \varnothing r_{AI}}{2} \right) \right)$.

Even if (11) holds, financial intermediaries might not approve loan requests. Especially if the relation of loan exposure to an applicant's net worth is comparatively high, lenders reject mortgage applicants in order to moderate default risk. Except for a fixed fraction of equity, residential property is mortgage financed which must be redeemed by periodical income. According to the applicant's budget constraint, a bank limits his mortgage exposure to his highest possible expenditure for housing purposes which forms a first mortgage lending constraint:

$$C1 : T_{max,i,1} = \frac{Y}{\left(\frac{\alpha}{\beta} + 1 \right)}. \tag{14}$$

As evidenced in previous research, the mortgage-to-income ratio, herein expressed by γ, serves as a reliable indicator to estimate borrower default (Ambrose

[9] As Sommervoll et al. (2010), Braun et al. (2022), and Braun (2023) we allow for $r_{AI} = r_d$. Following this approach, agents may decide about mortgage lending according to individual market expectations and balance sheet compositions.

[10] The opportunity costs c_t only consider costs out of forgone investments. To determine those, the mean of past average returns of T and AI is used since the potentially invested asset as well as its return is unknown. Operating costs that might derive for mortgage lending are not considered.

& Capone, 2000; Hakim & Haddad, 1999; Yang et al., 1998).[11] Thus, potential lenders calculate $\gamma = \left(\frac{T-E}{Y}\right)$ which is assumed to be oppositely associated with a borrower's probability of not defaulting. Resulting of this, q can be expressed by a decreasing function of γ, $q = q(\gamma)$. This leads to the second constraint of mortgage volume according to which a potential lender would only grant a loan that is not higher than the opposite of a borrower $i\prime s$ mortgage-to-income ratio times i's income, given his non-default probability:

$$C2 : T_{max,i,2} = \left(1 - \gamma_i\right) Y_i. \tag{15}$$

It is a common business practice that in housing finance, loan requests are confirmed against pledged collateral (Bester, 1985). Usually, the housing loans are secured by the financed property itself. Relying lending decisions on the collateral values of houses is a convenient way for banks to forgo costly screening of customers while at the same time being protected in the case of borrower default and reducing the risk of moral hazard (Aghion & Bolton, 1992; Hart, 1995; Manove et al., 2001). Several studies exist that evidence that banks base their lending approval on collateral values (Collyns & Senhadji, 2003; Freund et al., 1998; Herring & Wachter, 1999; Hilbers et al., 2001; Niinimäki, 2009).

Corresponding to this, we model a third credit constraint that relies on the collateral value of the financed dwelling. This in turn is highly associated with ongoing market dynamics and may be imposed by fluctuations. To determine the collateral value $CV_{k,i}$, banks refer to recent price information and adapt their own expectations. If real estate prices were flourishing in previous periods, banks imply a further appreciation and lend generously. In adverse market conditions, mortgage lending is restricted. Due to decreasing house prices, collateral values diminish making mortgage lending riskier. For diversification reasons, banks consider approving real estate loans despite falling prices up to a certain threshold. In this case, potential lenders also account for customer information. If price depreciations exceed this threshold, lending is further limited. Formally, banks constrain the applicant's i loan exposure to:

$$C3 : T_{max,i,3} = CV_{k,i} = \begin{cases} (1+e)(1+\rho)^2 P_{t-1} for \rho^{+} \\ \chi(1+e)(1+\rho) P_{t-1} for \rho^{-} > \psi, \\ \chi(1+e)(1+\rho) \frac{Y}{\left(\frac{\alpha}{\beta}+1\right)} for \rho^{-} < \psi \end{cases} \tag{16}$$

where e is a bank's perception of future price developments, ρ^{+} is a positive, and ρ^{-} a negative price change, χ is a risk discount, and ψ the threshold until which mortgage lending is advantageous out of diversification reasons although prices fell in previous periods.

[11] In this model setting, we restrain from modeling strategic default. By calculating the individual utilities of potential customers that are derived from owning housing, we ensure that only those agents enter the housing market who positively assess owning residential property and thus, want to avoid default.

This loan approval process is inherently procyclical and amplifies house price fluctuations. From the perspective of financial stability, the real estate market is one of the most decisive markets as due to collateralization practices, the financial accelerator mechanism occurs highly intensified. Since increasing housing prices increase the loan amounts needed to afford a residential property, house price appreciations put upward pressure on credit demand. As houses serve as collateral, higher property valuations in turn boost households' net worth which elevates borrowing capacity. These market mechanisms are further intensified by banks' expanded lending practices which are based on appreciated collateral values (Anundsen & Jansen, 2013). The excessive amplification of market fluctuations bears an enormous risk to the overall economy. Whether the *CCyB* succeeds in its purpose to minimize this is to be examined in the following of this research.

On top of collateralization, banks usually demand an initial amount of equity capital from potential borrowers. The required volume of down payment constitutes a fixed share of equity in relation to the price of the desired residential property which is $\varepsilon = \frac{E}{P_i}$. According to this, a fourth credit constraint banks impose is:

$$C4 : \frac{E}{P_i} \geq \varepsilon, \tag{17}$$

where E indicates the disposable amount of equity of a potential buyer which is derived from a uniform distribution on $E \sim U(0, 0.35)$, P_h the price of the dwelling the buyer desires to buy and ε indicates the demanded equity ratio. The equity constraint is an enclosed constraint that must invariably be met. A mortgage application can either be approved fully or it is rejected. Partial commitments cannot be granted. Given (14), (15), (16), and (17), the approved mortgage exposure is denoted by $T_i = \min(C1, C2, C3)$ while $C4$ holds.

Alternative Investment

In this model environment, the alternative investment AI constitutes the second risky investment option for banks. It is assumed to be a fully diversified set of assets and is referred to be the market portfolio. To mimic a diverse investment universe, we allow its fundamental value to follow a continuous time stochastic process. To model the price path of AI we use a geometric Brownian motion in which AI's fundamental value follows a geometric random walk with a constant mean change and a drift. AI's fundamental value is:

$$f_t^V = f_{t-1}^V + \mu - \frac{\sigma^2}{2} + \eta_{t-1}, \tag{18}$$

where f_{t-1}^V designates AI's log fundamental value of the previous period, μ its long-term expected drift, σ its standard deviation, and η_{t-1} a random walk for which $\eta_{t-1} \sim N\left(0, \sigma_\eta^2\right)$ holds.

We follow the approach of Lengwiler and Maringer (2011) and Braun (2023) in which AI's market price is not equal to its fundamental value. Instead, it is the result of agents' interaction. According to their perceptions of market behaviors and their individual balance sheet compositions, they decide whether to invest or disinvest in AI. Trading occurs via one central order book in which bids and asks are collected and matched oppositely using price priority.[12] The AI's market price p_M is the log-transformed mean of all transactions that have been conducted during one period:

$$p_{M,t} = \left(\frac{1}{N_{transactions,AI}} \right) \sum_{p=1}^{N} P_{bid}, P_{ask}. \tag{19}$$

Deviating from the approach of Lengwiler and Maringer (2011) and Braun (2023) we model a constantly liquid share market and prevent liquidity to dry up by introducing a market maker. Thus, we ensure that banks can trade the market portfolio whenever they want or need to. This seems reasonable as in the prevailing model environment AI represents any other investment opportunity for banks.

To account for banks' own perceptions about market developments and thus, to incorporate different investment strategies of banks, we include an agent-specific term $e_{m,AI}$ for which $e_{m,AI} \sim N\left(0, \sigma^2_{e_{m,AI}}\right)$ holds that considers the variability in the perception of the fundamental value. At the beginning of each period, a bank m conducts some research and obtains a private noisy signal which is:

$$s_{m,t} = (f^V_{t_{-1}} - p_{M,t_{-1}}) + e_{m,AI}. \tag{20}$$

This signal compares the previous fundamental value of AI with its market price and includes a bank's individual market expectation. Based on this, the agent m forms his expected fundamental value:

$$f^V_{exp,m} = f^V_{t_{-1}} + \mu + s_{m,t}. \tag{21}$$

As for any other risky business practices, Basel III rules apply when banks invest in AI. According to those, a specified amount of equity needs to be held to absorb potential losses (see "Regulatory Capital Adequacy Requirements including CCyB"). Arising opportunity costs for tied-up equity reduce the expected profit out of AI which is $\frac{f^V_{exp,m} - p_{M,t-1}}{p_{M,t-1}}$. To decide between mortgage lending and investing in the alternative investment, banks calculate:

$$r_{AI,eff,m} = \left(\frac{(f^V_{exp,m} - p_{M,t-1})}{p_{M,t-1}} \right) - \left(r_{wAI} * \left(\frac{\varnothing r_t + \varnothing r_{AI}}{2} \right) \right), \tag{22}$$

where the calculation of the opportunity costs equals the calculation of opportunity costs for mortgage lending (see Eq. (13)), adjusted to the respective risk weight.

If $r_{T,eff,m} \geq r_{AI,eff,m}$ holds, agent m decides in favor of financing housing investment. If the opposite is true, he buys AI. The decision between housing financing and investing in AI does, however, not only depend on the profit-maximizing investment opportunity. Instead, banks need to account for their current balance sheet composition as well as regulatory compliance before conducting business. If a bank fulfills regulatory requirements and has enough disposable free equity, it decides between

[12] Direct OTC trading is not possible.

the investment options with the intention to maximize profit. If disposable free equity is positive but scarce, banks may be limited in business activities. In case the *CAR* are violated, banks are forced to sell shares in order to generate profit and meet the *CAR* again. If this attempt is unsuccessful and all funds are exhausted which means that no saleable assets are left, the respective bank is declared to be bankrupt.

A buy order of an agent is placed at the expected fundamental value of *AI* plus a spread. Fire sales are placed diminishing the fundamental value by a spread to increase the probability of a sale. Accordingly, the bid / ask price of a bank *m* is:

$$\begin{aligned} P_{bid,m} &= f^{V}_{exp,m} + spread \\ P_{ask,m} &= f^{V}_{exp,m} - spread \end{aligned} \tag{23}$$

Baseline Computational Experiment

To analyze the effectiveness of the *CCyB* as a macroprudential tool of Basel III, we conduct a set of several computational experiments. The model designed and presented in the previous sections is used to generate numerical simulations that allow us to test whether the regulatory rule achieves its purpose to mitigate credit booms, to prevent spillover effects to the macroeconomy, and enhance financial stability.

To investigate these purposes, we create four different experimental environments: one standard scenario, and three shock scenarios. The first one represents an undisturbed market environment in the absence of any shocks that serves as a base scenario. The shock scenarios incorporate an exogenous shock that directly impacts endogenous market activity. In each experimental environment, we compare market conditions and the effectiveness of the regulatory rules in fostering financial and macroeconomic stability under two regulatory regimes. The *CAR*-regime represents market conditions in which banks need to comply with the microprudential rules only. The *CAR* + *CCyB*-regime reveals market conditions in which the national authority introduces the *CCyB* as a macroprudential stabilization factor depending on previous credit growth. We simulate 200 periods for each scenario.

To consider whether the regulatory purposes are met, we detect excessive credit growth by examining the volatility of credit in terms of credit volume and the number of granted mortgage loans. To account for spillover effects on the housing markets, we measure the intensity of price movements by calculating their standard deviation. The Z-score is used to account for the resilience of the banking sector. It measures banks' distance from insolvency and is a key indicator of financial stability (Boyd & Runkle, 1993; Lepetit & Strobel, 2015; Roy, 1952). To assess borrowers' risk and overall economic wealth, we measure the borrowers' non-default probability, the transaction rate of houses, their construction rate, and the rate of homeownership.[13]

[13] The transaction rate, the homeownership rate, and the construction rate are calculated as follows: $TransactionRate = \frac{N_{transactions,t}}{\min(N_{buyers,t}, N_{sellers,t})}$, $HomeownershipRate = \frac{N_{transactions,t}}{N_{potentialbuyers,t}}$, $\text{ConstructionRate} = \frac{N_{constructions,t}}{(N_{newsellings,t} + N_{leftover})}$.

Calibration of the Simulation Setting

The model is calibrated on empirical evidence, data obtained from the literature, or according to parameters that aim to capture real economies in terms of relations and conditions. The computational experiments are initially performed in a setting with a number of 60,000 potential buyers, 30,000 sellers, and 53 banks. Each of these agents owns a diverse set of individual features and market perceptions which ensures a high degree of heterogeneity. The initial market price of one unit of housing is set to $P_{h,t} = 2,500$ and the price development in previous periods is $\Delta P_{h,t-1} = 50$, and $\Delta P_{h,t-2} = 50$. After a sale has been conducted, the respective buyer and seller leave the market. The same holds true if a buyer was unsuccessful to buy a house for 10 periods. In this case, he is assumed to be too old to afford a future debt burden and he stays a tenant. In each period, a random number of potential buyers in a range of [60000,66666] and potential sellers in a range of [20,22] enter the housing market. Buyers' initial debt burden rate for investing in residential property is $r = 0.12$. This is the sum of a fixed redemption rate of $r_p = 0.1$ and an initial mortgage interest rate of $r_t = 0.02$.[14]

The financial market is populated by 53 banks.[15] Their initial balance sheet positions are calibrated on data obtained from BankFocus. Just like sellers and buyers, each bank is characterized by individual market perceptions and, according to this, forms its own investment strategy. In times of depreciating house prices, banks assess a risk discount to determine the collateral value of the financed property. According to German conditions, this is assumed to be 0.2 so that $\chi = 0.8$ (Bienert & Brunauer, 2007). The loan default rate for banks is set to $D = 0.01$.[16] If one bank leaves the market because of insolvency, a new bank enters it with the same initial balance sheet positions but with different expectations about market developments. Following this approach, we hold the number of banks on the market fix and rule out any effects that might occur because of changing market size while at the same time ensuring agents' heterogeneity.

The measures that determine the alternative investment AI are initialized to mimic the German stock index (DAX). The past return rate of AI is set to $r_{AI} = 0.084$, its past fundamental value to $f^{v}_{t-1} = 1,008$. To determine $AI's$ fundamental value we use a drift of $\mu = 0.1215$ and an annual volatility of $f^{V}_{t} = 0.192$.[17] The parameters to initially calibrate the model are summarized in Table 2.

[14] A rate of $r_t = 0.02$ represents the average mortgage interest rate in Germany from January 2012 until December 2021. This data is available at the German Bundesbank.

[15] This is the number of banks obtained from the BankFocus database which are classified as commercial banks according to the national Banking Act (Sect. 1 KWG), either grant mortgage loans to households or invest in alternative investment opportunities, and for which the respective balance sheet data was available. Group companies are represented by the parent company.

[16] The default rate of commercial banks is obtained from the ECB Statistical Data Warehouse.

[17] These parameters are calculated based on the daily price history of the German stock index (DAX) over the period from January 2012 to December 2021. The data is obtained from the Refinitiv Eikon database.

Table 2 Initial simulation parameters

Parameter	Description	Value
Buyers		
α	Preference for consumption	[0, 1]
α		
Υ	Income	[100, 1000]
e	Individual market expectation	[-0.1, 0.1]
E	Equity	[0, 0.35]
Sellers		
e	Individual market expectation	[-0.1, 0.1]
ς	Markdown ratio	0.95
Housing Market		
$P_{h,t}$	Price index	2500
P_t		
ΔP_{t-1}	Price change in t-1	50
ΔP_{t-2}	Price change in t-2	50
N_{Buyers}	Number of buyers	60,000
$N_{Sellers}$	Number of sellers	30,000
r_p	Redemption rate	0.1
r_t	Loan interest rate	0.02
Credit Institutions		
e	Individual market expectation	[-0.1, 0.1]
e_{AI}	Individual market expectation	[-0.192, 0.192]
r_d	Default rate of return	0.001
χ	Loan-to-value	0.8
Ψ	Threshold of price decline	0.03
D	Loan default rate	0.01
Financial Market		
Financial Market		
r_f	Risk free interest rate	0.01
r_{AI}	Market return	0.084
f_{t-1}	Fundamental value of AI	1008
μ	Drift	0.1215
σ	Volatility	0.192
p_m	Market price of AI	1000
Θ	Threshold of mortgage growth	0.05

Base Scenario

In the first simulation scenario, we create an experimental environment that mimics the housing market in the absence of any shocks. The economic agents enter the market, evaluate ongoing market conditions and form individual behavioral strategies. According to their utility for housing investment, buyers seek to buy a home, limited by their budget constraints. Sellers track previous market developments and decide whether to state an offer. Following the purpose to maximize profit but being constrained in

Table 3 Statistical key variables of the base environment

Base Scenario		CAR	CAR + CCyB
House Price	Min	1704,531	1741,796
	Max	3465,673	3306,283
	Mean	2453,726	2505,115
	Std	413,051	362,501
Mortgage Interest Rate	Min	0,011	0,008
	Max	0,065	0,061
	Mean	0,036	0,038
	Std	0,013	0,011
Non-Default Probability	Min	0,000	0,000
	Max	0,877	0,906
	Mean	0,664	0,760
	Std	0,059	0,057
Transaction Rate	Min	0,000	0,000
	Max	1,000	0,972
	Mean	0,185	0,179
	Std	0,225	0,224
Homeownership Rate	Min	0,000	0,000
	Max	0,510	0,570
	Mean	0,124	0,101
	Std	0,013	0,013
Construction Rate	Min	0,000	0,000
	Max	2,600	2,818
	Mean	0,179	0,115
	Std	0,046	0,072
Loan Amount	Min	1,000	1,000
	Max	1.103.256,65	914.432,12
	Mean	181.888,61	142.829,18
	Std	23.222,66	49.163,38
No. of Loans	sum	1924	1857
Z-score	Min	2,286	2,455
	Max	2,994	3,188
	Mean	2,714	2,923
	Std	0,168	0,180

business activities due to the regulatory requirements of Basel III, banks opt for financing residential property or investing in an alternative investment portfolio. The interaction of market participants creates endogenous housing market cycles. Changing market conditions feedback on the financial market and vice versa and the interplay between mortgage borrowers and banks impact the stability of the financial sector.

To analyze the effectiveness of the regulatory policies, we evaluate the dynamics of the key variables during the simulation runs. Table 3 reports the statistical values of the baseline *CAR*-scenario and contrasts them to those of the *CAR* + *CCyB*

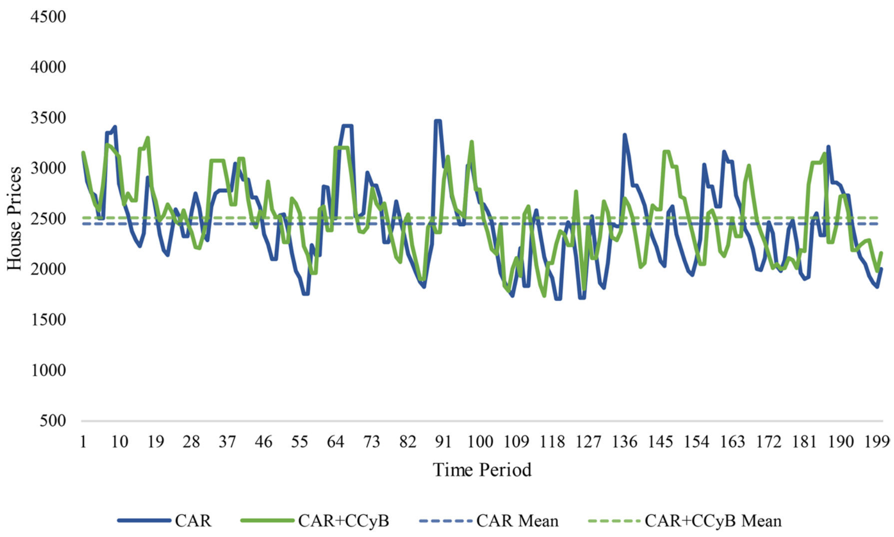

Fig. 1 House price movements in the base environment

-scenario. The measures reveal that in both experimental environments, the house prices fluctuate cyclically around their mean. These movements are visualized in Fig. 1. The minimum price of dwellings in the *CAR*-scenario falls below this of the $CAR + CCyB$-scenario (1704,534 vs. 1741,796). This indicates that the *CCyB*, whenever it is announced by national authorities, prevents house prices to fall down sharply. The indication is affirmed by the graphical illustration of house price movements in Fig. 1. The ongoing dynamics in the *CAR*-scenario push prices to deep troughs if the real estate market experiences a downturn. If prices reached a peak and depreciated in previous periods, banks progressively constrain mortgage lending. As collateral values decline, they substitute higher-risk credit businesses with higher-yielding alternative investment opportunities. The downward trend ends in a real estate price crunch. Such deeper price declines do not appear if banks only need to comply with the *CAR* of Basel II. Following the regulatory rule of Basel III, banks need to hold an additional amount of equity in times of excessive positive price trends. The built capital cushion shall be released in adverse market developments. Less strict equity requirements cheapen mortgage lending for banks and render it more attractive compared to investing in *AI*. As a result, in the $CAR + CCyB$ -scenario, banks grant mortgages more generously in times of depreciating house prices than in the *CAR*-scenario. The release of the *CCyB* ensures sufficient credit supply in downward trends. This induces prices to turn around earlier and thus averts deep price falls.

The maximum housing price is quite lower in the *CCyB* environment. In times of excessive credit growth, the activated *CCyB* is intended to stop disproportionate price increases by making lending more expensive. However, if prices are rising over time, collateral values rise likewise. Rising property values make banks less cautious and they lend more generously. Furthermore, increasing collateral values make the LTV of

Table 4 Market cycle properties of the base environments

Base Scenario	CAR	CAR + CCyB
Average Cycle Length	9.9	8.9
No. of Cycles	20.0	20.9
No. of Outbreaks	47.4	34.7

Table 4 displays some properties of the housing market cycles occurring in the two regulatory regimes. One cycle starts and ends with the mean of the respective housing price. An outbreak is defined as a price movement up or below the mean, ± its standard deviation. The measures are computed for the whole simulation of 200 periods

borrowers decline. This creates an offsetting effect. Although mortgage lending gets more expensive because of higher equity requirements, these requirements are based on the LTVs of home buyers which drop with rising collaterals. Whereas the *CCyB* succeeds in preventing house prices from deep price falls, it often allows prices to appreciate nearly to the same extent as with microprudential *CAR* only. Nevertheless, the *CCyB* is able to prevent very high peaks as can be seen in Fig. 1. Higher troughs and lower peeks lead to a marginally higher mean real estate price which is 2505.115.

According to macroeconomic stability, the *CCyB* succeeds well. The macroeconomic tool manages to reduce the standard deviation of housing prices and thus their volatility and stabilizes housing market cycles. Table 4, which displays the properties of the endogenously created housing market cycles, confirms this conclusion. The *CAR* + *CCyB*-scenario features an average cycle length of approximately 9 periods (8.9) which is lower than approximately 10 periods in the *CAR*-scenario. Thus, a higher number of cycles due to faster-induced turnarounds of price trends occur in the *CAR* + *CCyB*-scenario (20.0 vs. 20.9). The lower number of outbreaks (34.7) fosters the previous indication that the *CCyB* stabilizes housing market cycles.

In both, the *CAR*-scenario and the *CAR* + *CCyB*-scenario, the lowest equity a bank needs to hold is the microprudential *CAR*-level. In the second scenario, however, the equity requirements are extended in times of excessive house price appreciations. The average amount of equity that needs to be held in the *CAR* + *CCyB* -scenario thus exceeds this of the *CAR*-scenario. An increase in the cost of lending lifts mortgage interest rates to 0.038 instead of 0.036. As housing investment gets more expensive, more prosperous borrowers in terms of higher initial equity and lower LTVs will get a loan preferentially. This makes the non-default probability in the *CAR* + *CCyB*-scenario exceed that of the *CAR*-scenario (0.760 vs. 0.664). This apparently positive effect coincides, however, with a lower transaction rate of houses (0.179 vs. 0.185), a lower rate of homeownership (0.101 vs. 0.124), and a lower construction rate (0.115 vs. 0.179). In line with the preceding results, the average loan amount granted for residential purposes as well as the total number of mortgages is less in the *CAR* + *CCyB*-scenario than in the *CAR*-scenario.

To measure the solidity of the banking sector, we account for the overall Z-score of the financial market in both experimental environments. The mean Z-score in the *CAR* + *CCyB*-scenario is 2.923 and outperforms this in the *CAR*-scenario of 2.714.

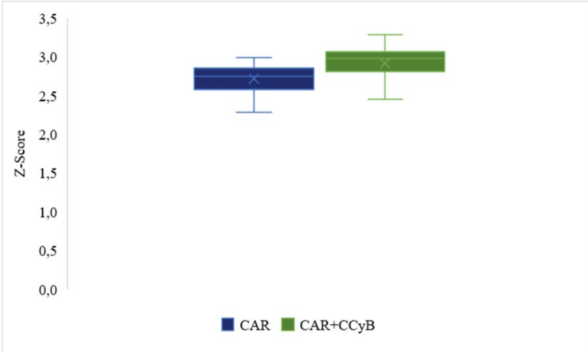

Fig. 2 Z-scores of the base environment

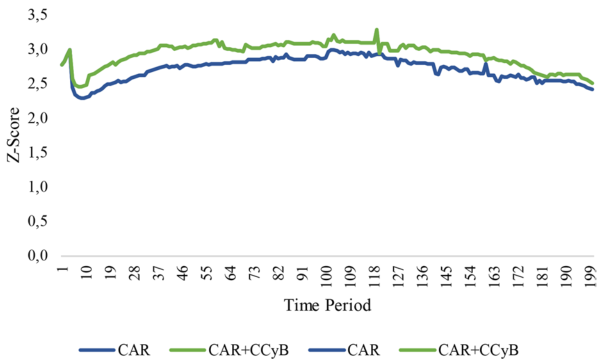

Fig. 3 Development of Z-scores in the base environment

This holds true for the whole set of interacting banks. Figure 2 illustrates the distribution of the Z-scores. It reveals that not only the mean resilience of the banking sector increases which could have been caused by a few very stable institutions but also the resilience of all banks. Figure 3 shows the evolution of the mean-Z-Sore over time. In both scenarios, the development is very stable and without remarkable outbreaks. This indicates that on average financial institutions conduct business steadily in both experimental environments. Over the whole simulation period, the mean value of the Z-score in the $CAR + CCyB$-scenario reaches the same or a higher level than in the *CAR*-scenario. The higher banking soundness in the $CAR + CCyB$ -scenario is due to two different reasons. First, the higher average equity conditions for banks equip the financial market with more loss-absorbing capital and make banks more resilient in times of economic downturns. Second, lower standard deviations of mortgage interest rates and less risky borrowers in the $CAR + CCyB$-scenario indicated by a higher non-default probability lower banks' business risk.

According to the experimental results, we conclude that in dynamic market conditions and in the absence of any shocks, the *CCyB* is an effective macroeconomic tool as it succeeds in stabilizing the housing market and the financial market. However, it should be taken into account that despite positive impacts, it also constrains macroeconomic market activities in the housing market and restricts homeownership for borrowers with lower initial wealth or lower income. This, in turn, might negatively impact an economy's wealth, health, and social concerns.

Simulation of Shocks

Due to the close interconnectedness of the financial markets and the real economy, endogenously created market conditions may be disturbed by occurrences in adjacent markets. Thus, we examine the impact of several shocks from different origins on the dynamics of the housing and the financial market. These shocks are a financial shock, a positive housing demand shock, and a housing bubble and will be investigated in the following sections.

Financial Shock

The first shock we investigate is a financial shock incorporated by an exogenous increase in interest rates.[18] To make sure that the outcomes are comparable, we lock the random numbers for the simulation scenarios and run 10 periods in the absence of any shocks. In period 11, the shock hits the market unexpectedly. Following this approach, we ensure that the changes that occur in the housing market are only due to the shock.[19]

Figure 4 shows the effects of a positive interest rate shock on the development of housing prices and their means in an environment in which banks need to comply with *CAR* only and one in which they need to build a *CCyB* additionally. Since random numbers are locked for both simulation scenarios, the market develops equally to the base scenario in the absence of any shock. When the shock sets in, in both scenarios, the shock spreads to the housing market and prices are clearly affected by the rise in interest rates. The positive shock boosts mortgage interest rates. This elevates expenditures for residential property and makes housing investment less affordable. Higher lending rates, in turn, depress demand for mortgage loans. The decline in credit diminishes the demand for homeownership, dragging down house prices. These attenuation effects are amplified by banks' borrowing constraints. In times of depreciating house prices, banks narrow loan offers (see Eq. 16) due to rising risk and the gain of the attractiveness of alternative investment opportunities. The decline in house prices depresses collateral values, furtherly tightening borrowing conditions. This financial accelerator mechanism amplifies ongoing market conditions, pushing prices into recession.

In both the *CAR*- and the $CAR + CCyB$-scenario the implications of the shock set in with a short delay. Even after the shock occurs in period 11, prices follow the usual cyclical patterns developed by the behavior of interacting agents and experience a short upturn. This mimics the sluggishness of housing prices that can also

[18] A rise in interest rates may have different reasons and might origin from different channels, e.g. an increase in the key interest rate by central banks, disruptions in the construction industry, war. We anticipate a general mark-up of mortgage interest rates by banks of 0.05. Table 12 in the appendix summarizes the variations of model assumptions in the shock scenarios. For the rest of the model parameters, the calibration stated in Table 2 holds.

[19] The average length of housing market cycles in the base scenario is 10 (see Table 4). Introducing a shock right afterwards ensures that the market develops freely affected by the shock.

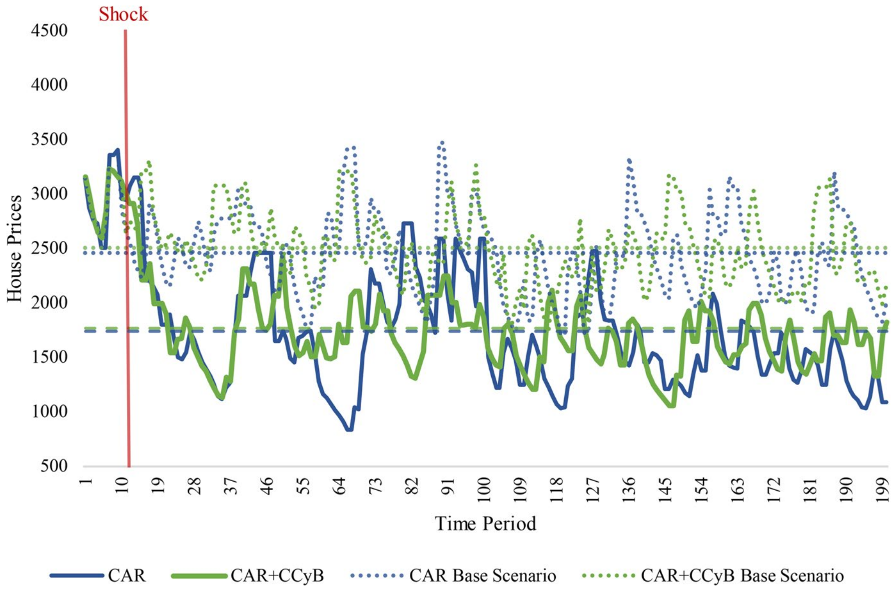

Fig. 4 House price movements in the financial shock environment

be observed in real markets. Economic agents perceive ongoing market changes and update their expectations afterwards. These processes cause the market to react within a time lag. As soon as agents' perceptions are updated, the housing market experiences a deep bust. Due to the previously described interdependent mechanisms, prices are pushed down sharply. Although small corrections occur (Fig. 4), they are not able to reverse the ongoing depression for about 20 periods. Neither does the macroeconomic *CCyB* mitigate its extent. The price behavior in the micro- and macroprudential regime is almost identical. Although the regulatory authority imposes banks to hold additional capital in appreciating times before the shock hits the market, the release of the previously implied buffer is not able to mitigate the extent of the exogenous interest rate shock that hit the market unexpectedly. This reveals that the effectiveness of the macroprudential tool depends on how much buffer has been built up in the previous periods and further indicates that its effectiveness might depend on the magnitude of the shock.

After an extended period of depreciation in the housing market, the trend ends when market participants have factored in the changed market conditions. In both regimes, prices start to rise and proceed with their cyclical pattern. As mortgage lending is still expensive due to the increase in interest rates, the level of house prices falls below the base scenarios which are also portrayed in Fig. 4. Although the *CCyB* is not able to prevent the housing market to crash when a positive interest rate shock hits the market, it performs well in mitigating sharp price outbreaks in the aftermath of the crisis. When there is no macroprudential policy in place, housing market cycles are distinct with high peaks and deep troughs. Due to high lending costs, the demand for housing and credit fluctuates strongly. Uncertainties in market developments increase its vulnerability to crises. In the *CAR* + *CCyB*-regime in contrast, the cyclical movement of house prices is remarkably mitigated. Excessive upturns are prevented by higher capital requirements and downturns are softened by releasing them. Although the *CCyB* fails to prevent a housing market crisis and to mitigate the recessionary effects of a financial shock, it performs well in dampening the amplification effects of the borrowing constraint channel in the aftermath of the shock. The longer the simulation takes, the more stable the market gets in both scenarios which leads to the conclusion, that when the number of paths approaches to infinity, the average among the paths converges to a quite stable market.

Table 5 contains the statistical measures of the investigated key variables of the two regulatory regimes. The positive interest rate shock spreads to the housing market by the elevated mortgage interest rates which directly impact the demand for credit. Lowered credit volumes spill over to the demand for properties which negatively affects the price level of houses. In both the *CAR*- and *CAR* + *CCyB* -scenario the minimum, the maximum, and the mean price is lowered compared to the base scenarios. As in the environment without any shocks, the minimum value of the *CAR*-scenario which is 833.005 falls below that of the *CAR* + *CCyB*-scenario (1057.514) whereas maximum values are quite equal (407.500 vs. 3232.250). Although the price development is identical before the shock hits the market and during the recession, the *CAR* + *CCyB*-scenario outperforms the *CAR*-scenario in terms of housing market stability. This is indicated by a lower standard deviation in the *CAR* + *CCyB*-scenario that amounts 420.755. Due to the lowered house price fluctuations in the aftermath of the crisis, the *CCyB* is effective in stabilizing the housing market overall.

As mortgage interest rates are the channel through which the shock on the financial market spills over to the housing market, they are significantly increased. As in the base scenario, the mortgage interest rates with *CCyB* are slightly higher (0.084 vs. 0.090). This is in line with the increased capital requirements during the shock recovery phase that prevent excessive credit growth. Through the inverse relationship of the mortgage-to-income ratio and the non-default probability of borrowers (see “Mortgage Supply”), higher housing expenditures amplify the riskiness of credit exposures and sharply decrease borrowers’ probability of not defaulting. As higher capital requirements tighten banks’ business activities, banks will lend to customers with higher LTVs in the *CAR* + *CCyB*-regime which lifts the non-default probability to 0.291 compared to 0.272 the *CAR*-regime.

Similar to the base scenario, the lifted capital requirements in the *CAR* + *CCyB* -scenario affect activities in the housing market restrictively and limit transaction rate, homeownership rate, and construction rate to a lower level than without *CCyB*. In the *CAR* + *CCyB*-scenario, the mean transaction rate is 0.092, the homeownership rate 0.098, and the construction rate 0.056 while in the *CAR*-scenario they reach 0.180, 0.177, and 0.069. Compared to the base environment, the ratios are significantly reduced due to higher lending costs. The loan amount as well as the number of accepted credit exposures is significantly smaller in the shock environment than in the base environment and the values of the *CAR* + *CCyB*-regime fall below the *CAR*-regime.

Table 5 Statistical key variables of the financial shock environment

Financial Shock		CAR	CAR + CCyB
Market Price	Min	833,005	1057,514
	Max	3407,500	3232,250
	Mean	1731,648	1767,351
	Std	533,323	420,755
Mortgage Interest Rate	Min	0,058	0,063
	Max	0,114	0,121
	Mean	0,084	0,090
	Std	0,015	0,015
Non-Default Probability	Min	0,000	0,000
	Max	0,594	0,627
	Mean	0,272	0,291
	Std	0,159	0,153
Transaction Rate	Min	0,000	0,000
	Max	1,000	1,000
	Mean	0,180	0,092
	Std	0,248	0,237
Homeownership Rate	Min	0,000	0,000
	Max	1,000	0,600
	Mean	0,114	0,098
	Std	0,177	0,136
Construction Rate	Min	0,000	0,000
	Max	3,333	0,786
	Mean	0,072	0,056
	Std	0,069	0,027
Loan Amount	Min	1,000	1,000
	Max	630.728,99	493.486,46
	Mean	112.554,90	84.381,16
	Std	45.588,42	21.707,10
No. of Loans	sum	1011	837
Z-score	Min	2,492	2,813
	Max	2,999	3,289
	Mean	2,862	3,161
	Std	0,099	0,094

Whereas the housing market is hit by an exogenous interest rate shock that generates high volatility in housing prices, the Z-scores of both regulatory schemes exceed this of the base scenarios, indicating higher banking soundness. Increased interest rates raise financial institutions' profits. These profits render the financial market a profound equity base that increases its solidity. Considering the low values of the non-default probability of borrowers, the assumed effect on banks' stability would be the other way around. The standard deviation of mortgage interest rates reveals, however, that profit out of mortgage lending is nearly as stable as in the base scenarios. This fact

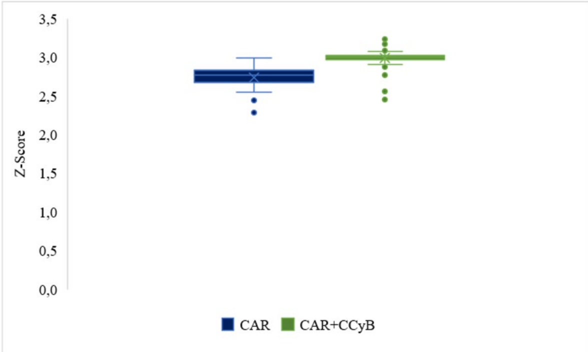

Fig. 5 Z-scores of the financial shock environment

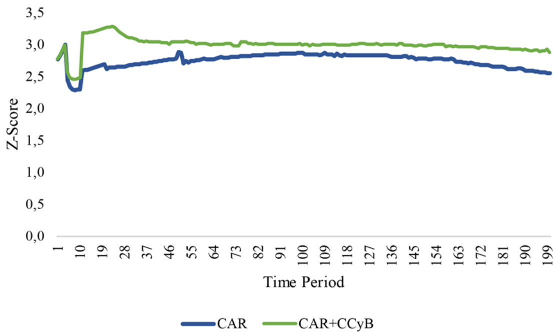

Fig. 6 Development of Z-scores in the financial shock environment

indicates that in an environment with a positive interest rate shock, banks, even more, constrain lending to borrowers with initial wealth or favorable LTV ratios. The impact of those loan-granting policies on the rest of the population is indicated by a decreasing transaction, homeownership, and construction rate in the shock scenario. Figure 5 displays the mean Z-scores of both regulatory regimes. As in the base scenarios, the *CAR* + *CCyB*-regime achieves higher values for the interactive banks and achieve a mean value of 3.116 vs. 2.862 in the *CAR*-scenario. The development of the mean Z-score over time (Fig. 6) reveals that banking soundness is only slightly affected by the positive interest rate shock. In the aftermath of the shock, the values remain quite stable in both the *CAR*- and the *CAR* + *CCyB*-regime whereas the second one exceeds this of the first one steadily. The high values of Z-scores in this shock scenario indicate that only accounting for microprudential measures is not sufficient to evaluate the impact of occurrences on the overall economy. Instead, macroeconomic effects need to be investigated that can be effectively lowered by macroprudential policies.

Relating to overall stability measures, the *CCyB* is effective in stabilizing the housing as well as the financial market in the aftermath of an exogenous positive interest rate shock. These results are verified by Table 6 which shows the properties of cycles under the *CAR*- and the *CAR* + *CCyB*-regime if a positive interest rate shock hits the market unexpectedly. Under the *CAR* + *CCyB*-regime, the average length of housing market cycles is lowered to 9.0 due to earlier initiated turnarounds and the number of outbreaks is reduced from 79.0 to 51.0.

Table 6 Market cycle properties of the financial shock environment

Financial Shock	CAR	CAR + CCyB
Average Cycle Length	18.4	9.0
No. of Cycles	10.9	18.5
No. of Outbreaks	79.0	51.0

Table 6 displays some properties of the housing market cycles occurring in the two regulatory regimes. For details see Table 4

Positive Demand Shock

The second shock we investigate is a positive housing demand shock incorporated as an increase in preferences for housing on the demand side.[20] Similar to the financial shock examined in the previous chapter, the housing demand shock is unanticipated by market participants and hits the market unexpectedly in period 11. The periods before the shock sets in are hold fix.

The shock generates expansionary effects in the housing market. The increase in the weight of residential property in the utility function for borrowers fuels the demand for housing. This pushes prices upwards and leads to high minimum, maximum, and mean prices under both regulatory regimes. In the *CAR*-scenario, the mean price level reaches 3247.530 which is slightly lower than this of the $CAR + CCyB$ -scenario (3261.565). The supply still develops endogenously by the perceptions and expectations of the economic agents. The increased demand cannot fully be absorbed by the housing supply, generating a sellers' market and driving house prices upwards. Figure 7 contrasts the development of dwelling prices and their means of the *CAR*- and $CAR + CCyB$-regime in the demand shock environment and compares them to the baseline scenarios. Until the shock hits the market in period 11, in both regimes, the price developments are similar to the base scenario. As soon as potential house buyers put more emphasis on being a homeowner, prices drift upwards, experiencing high positive peaks during the simulation, especially in the *CAR*-only regime. Positive price trends reverse sharply to the upper price level of the baseline scenario. If banks only need to comply with microprudential regulatory measures, the house price cycles are distinct. Price appreciations lead to high peaks which are followed by recessionary periods that end in deep busts. The extent of the fluctuations strongly corresponds to those of the *CAR* base scenario (see Table 7). In the environment where the *CCyB* is installed, house price movements are flattened. The macroeconomic tool mitigates excessive price increases and softens downturns also to a similar extent as it does in the $CAR + CCyB$ base scenario (Table 7). These results show that a positive housing demand shock directly affects housing prices, leading them to a higher level. However, compared to the baseline scenarios, the stability indicated by the standard deviation of housing prices in Table 7 amounts 450.363 in the *CAR*-scenario and 359.012 in the $CAR + CCyB$-scenario and thus, is not negatively impacted.

[20] The increase in preferences for housing demand is incorporated in the utility function of potential buyers by the parameter α with the following properties from period 11 onward: $\alpha \sim N(0,1)$, $\mu = 0.2$ and $\sigma = 0.02$. Table 12 in the appendix summarizes the variations of model assumptions in the shock scenarios. For the rest of the model parameters, the calibration stated in Table 2 holds.

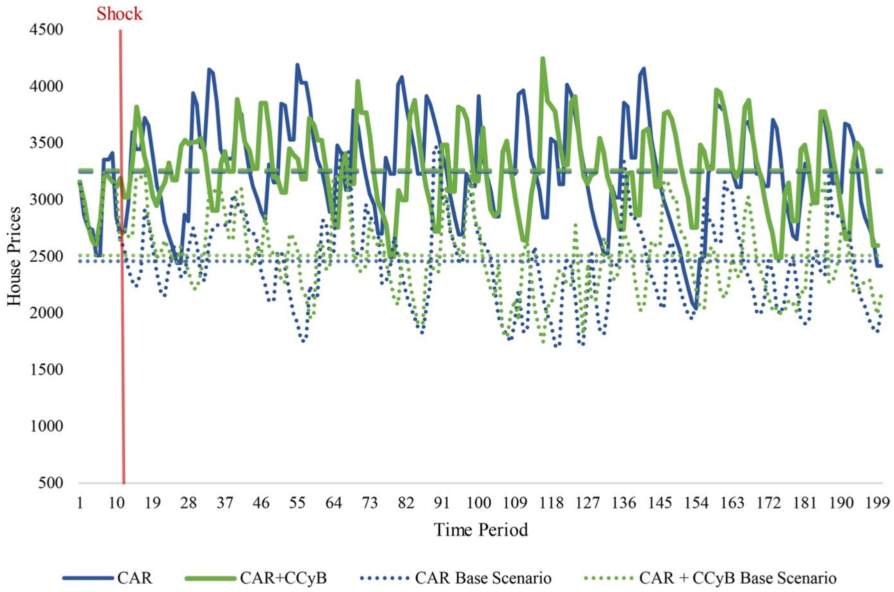

Fig. 7 House price movements in the demand shock environment

Whereas the reactions of the housing market to the financial shock set in with a delay, the housing demand shock affects prices immediately. This reveals that the transmission time and the impact of the shock are addicted to its origin.

The increased demand for buying a residential property that fuels house prices spill over to the financial market through greater demand for credit. The mean mortgage volume granted per period of the *CAR*- and the *CAR* + *CCyB*-regime strongly exceeds this of the base scenarios and the financial shock scenarios (see Table 7). The number of granted loans, in contrast, is comparable to those of the base scenarios. This reveals that the increase in mortgage volume is induced by the rise in house prices and mimics one spillover effect from the housing market to the financial market. Rising house prices further impact mortgage lending as they soften the borrowing constraints for potential buyers. Higher collateral values allow borrowers to extend credit volume which in turn further drifts up prices, launching the financial accelerator mechanism and reinforcing ongoing market developments. The dampening effects of the *CCyB* on these market dynamics are reflected in the loan amount (341,900.17) and the number of accepted mortgages (1824). Both measures are below those of the *CAR*-regime. Forcing banks to hold additional capital mitigates excessive credit growth and attenuates self-reinforcing effects that arise from the interplay of the housing and the financial market.

As a response to excessive demand for credit, banks raise their mortgage interest rates in comparison to the base scenarios (Table 7). Since the introduction of the *CCyB* makes mortgage lending more expensive for banks, it has an additional increasing effect on interest rates. This cost-increasing effect of mortgage borrowing restrains the demand for housing and counteracts excessive house price appreciations. Higher collateral values counterbalance higher expenditures for housing investment,

Table 7 Statistical key variables of the demand shock environment

Demand Shock		CAR	CAR + CCyB
Market Price	Min	2437.608	2497.032
	Max	4188.839	4044.763
	Mean	3320.839	3286.535
	Std	421.831	318.572
Mortgage Interest Rate	Min	0.009	0.022
	Max	0.088	0.097
	Mean	0.045	0.052
	Std	0.014	0.013
Non-Default Probability	Min	0.000	0.000
	Max	0.848	0.819
	Mean	0.645	0.662
	Std	0.106	0.080
Transaction Rate	Min	0.000	0.000
	Max	1.000	1.000
	Mean	0.191	0.176
	Std	0.024	0.023
Homeownership Rate	Min	0.000	0.000
	Max	0.358	0.373
	Mean	0.060	0.083
	Std	0.077	0.094
Construction Rate	Min	0.000	0.000
	Max	2.833	1.500
	Mean	0.137	0.134
	Std	0.343	0.244
Loan Amount	Min	4,338.22	1.00
	Max	1,353,992.13	1,026,678.23
	Mean	572,608.71	355,300.17
	Std	36,506.15	28,752.83
No. of Loans	sum	1870	1837
Z-score	Min	1.662	2.617
	Max	3.426	3.096
	Mean	2.132	2.770
	Std	0.273	0.080

letting the non-default probability of borrowers decrease in comparison to the base scenarios. The need for additional capital in the $CAR + CCyB$-environment counteracts this effect and leads to an outperforming non-default probability of 0.596 compared to 0.560. The extended capital requirement has a tightening effect on mortgage granting and makes it more secure. It is able to cushion future probable losses and makes the probability of not defaulting increase compared to the *CAR*-environment.

The transaction rate and the construction rate exceed those of the base scenarios and the financial shock scenarios. As the existing supply of houses is not able to satisfy the extensive demand, construction firms extend their business activities and

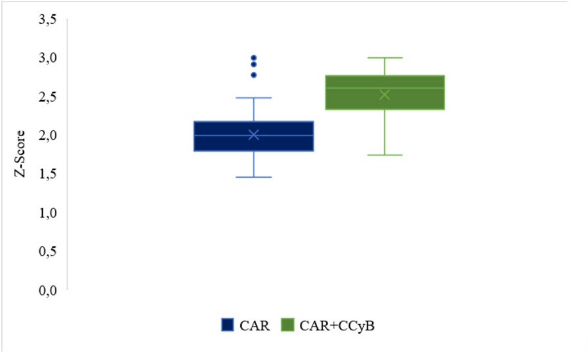

Fig. 8 Z-scores of the demand shock environment

build new dwellings. Both variables are slightly depressed in the *CAR* + *CCyB*-scenario as the macroprudential measure has a restrictive effect on market activities. The homeownership rate of 0.056 in the *CAR*-scenario and 0.074 in the *CAR* + *CCyB*-scenario falls below this of the scenarios described in the previous chapters. Due to the positive housing demand shock that induces rising house prices, the number of potential home buyers rises excessively whereas the supply of dwellings is limited. A huge amount of unsatisfied housing demand diminishes the homeownership rate. As the *CCyB* has a limiting effect on house price appreciations, it positively affects the rate of homeowners and generates a higher value than in the *CAR*-environment.

The Z-score of the two regulatory schemes in a market that experiences a positive housing demand shock is lower than in the respective baseline and financial shock scenarios. It amounts to 2.432 under the *CAR*-regime and 2.870 under the *CAR* + *CCyB*-regime. This indicates that an external shock affects the soundness of the financial market more than a shock that has its origin in the financial market. And though, as in the previous simulation scenarios, the *CCyB* performs well in stabilizing financial institutions in the event of a positive housing demand shock and makes them more resistant to potential crises. This can also be seen in Fig. 8 which visualizes the mean Z-scores of the interacting banks in the *CAR*- and the *CAR* + *CCyB*-regime. Figure 9 shows the development of the Z-score over time. The Z-scores in the *CAR*-environment fluctuate more strongly than in the *CAR* + *CCyB*-environment. These variations also exceed those in the baseline and the financial shock scenarios.

Table 8 summarizes the cycle properties of both regulatory schemes in the event of a positive housing demand shock. The measures support previous results and reveal that the macroprudential *CCyB* prevents excessive housing market cycles. It lowers ongoing price appreciations or depreciations and induces market trends to turn earlier. This is revealed by a lower average cycle length (6.8 vs. 10.4) which is accompanied by a higher number of cycles. Fewer outbreaks in the *CAR* + *CCyB*-regime (29.0 vs. 39.0) indicate that the cycles oscillate closer around their mean value.

As the simulations show, the *CCyB* is an effective tool to mitigate excessive house price increases and to moderate spillover effects to the financial market in the event of a positive housing demand shock. Forcing banks to hold additional capital in times of excessive credit growth dampens house price appreciations. The smoother development

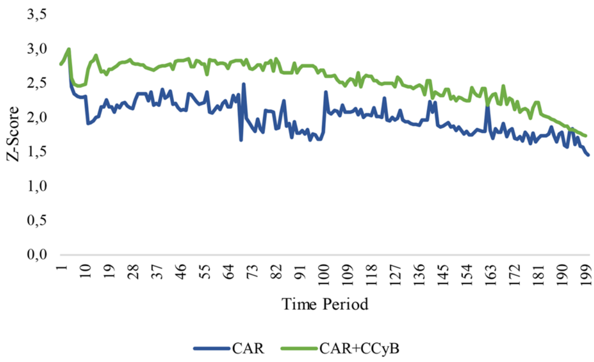

Fig. 9 Development of Z-scores in the demand shock environment

Table 8 Market cycle properties of the demand shock environment

Demand Shock	CAR	CAR + CCyB
Average Cycle Length	10.6	7.2
No. of Cycles	18.8	27.6
No. of Outbreaks	41.0	30.0

Table 8 displays some properties of the housing market cycles occurring in the two regulatory regimes. For details see Table 4

of housing prices is transmitted to the rest of the economy more softly and thus, the *CCyB* moderates the impact of a positive housing demand shock on the macroeconomy.

Housing Bubble

The perceptions and expectations of economic agents are decisive key indicators for the development of the housing market. In this section, we model a housing bubble similar to that which caused the latest financial and economic crisis and evaluate the impact of agents' distinct expectations about future housing demand appreciations on the key variables of the housing and the financial market. In this model environment, agents expect housing demand to rise at a certain point of time in the future. This expectation may be driven by different macroeconomic developments, such as a positive news shock about housing productivity, or housing supply, monetary policy that indicates a decline in future interest rates, or an upcoming subsidy for homeownership.

In contrast to the financial shock and the housing demand shock described in the previous sections, in this model environment, the agents anticipate a future change in market conditions. As a result, the investigated shock does not have a fundamental basis but is expectation driven by market participants. To simulate this, we assume that potential home buyers expect an increase in demand to occur in period 20. In period 20, however, the expectation does not materialize.[21]

[21] For a summary of the variations of model assumptions in the shock scenarios see Table 12 in the appendix. For the rest of the model parameters, the calibration stated in Table 2 holds.

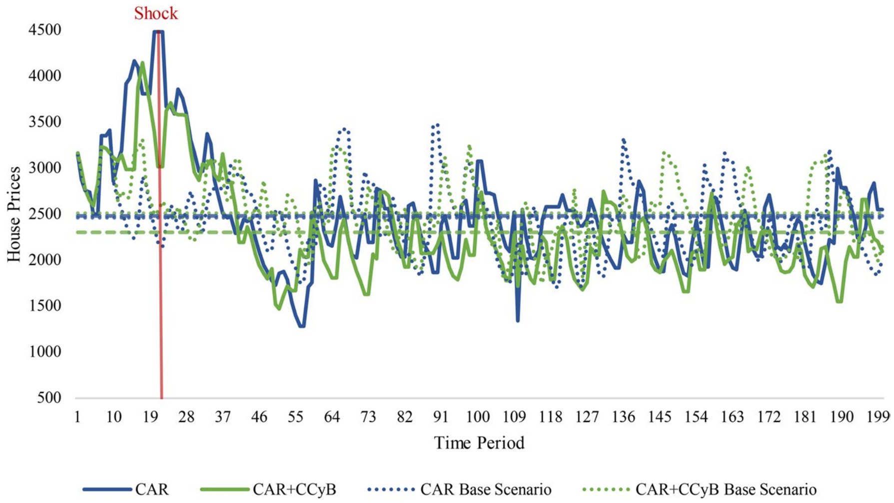

Fig. 10 House price movements in the housing bubble environment

The positive anticipations of the interacting agents generate expansionary effects in the housing market that are visualized in Fig. 10. The expectations of a future increase in housing demand fuel prices immediately. Potential home buyers' assumptions of a higher demand for residential property are associated with rising expenditure for housing investment in the future and suppressed supply. As a result, potential buyers invest in housing today for speculative purposes, causing current demand to rise and inducing inflationary effects on prices. As in "Positive Demand Shock", these market mechanisms spill over to the financial market and fuel mortgage lending as well as mortgage interest rates. Similar to the positive demand shock scenario ("Positive Demand Shock"), house prices react without any delay. This supports the hypothesis that those markets in which a shock originates record the first effects as transmission mechanisms are short. The expansionary effects appreciate house prices during the expectation period to a higher level compared to the base scenarios. The optimism about future housing demand generates a housing bubble in both the *CAR*- and the $CAR + CCyB$-scenario inducing a macroeconomic boom characterized by a co-movement between excessive residential investment, house price increases, and granted mortgage loans. During the simulation, the price level of the $CAR + CCyB$-scenario is mostly lower than this of the *CAR*-scenario. This indicates the $CCyB\prime s$ effectiveness in mitigating excessive price increases. However, it is not successful in preventing a housing bubble to occur. In the $CAR + CCyB$ -scenario, expectations of a future increase in housing demand push current prices upwards nearly to the same extent as in the *CAR*-scenario. When the anticipated demand increase does not materialize in period 20, in both investigated regulatory regimes prices follow their ongoing trend for a few more periods and fall into recession afterward. The failed expectation makes the housing bubble burst and causes house prices to collapse. The previous self-reinforcing expansionary effects reverse and impact the macroeconomy oppositely. The release of the *CCyB* in times of economic downturns only cushions the huge price decline marginally.

The impact of a housing bubble induced by an expected increase in housing demand in the future is more distinct than an unanticipated positive interest rate shock ("Financial Shock") and an unanticipated positive housing demand shock ("Positive Demand Shock"). The price drop that follows a housing bubble is deep and it takes long for the housing market to recover. After an extended period of price depreciation, the market turns, and prices slowly approach the price level of the base scenarios. In the case of unanticipated shocks, economic agents price in changing environments earlier. Expectations about future market conditions distort the investment plans of potential home buyers, price levels, and mortgage borrowing levels that suddenly reverse when the expectations do not realize. The unrealized anticipations cause a dramatic drop in the housing market and aggregate variables fall below their initial level. During the recovery phase, the macroprudential *CCyB* affects house price movements positively. It induces prices to turn around earlier ending the recession at a higher level. In the aftermath of the burst housing bubble, house price movements are more stable and less distinct in the *CAR* + *CCyB*-scenario. Similar to the financial shock environment, the *CCyB* is not able to prevent the crisis caused by an anticipated increase in housing demand but it is successful in stabilizing housing markets in the aftermath of the crisis.

Table 9 contains the investigated key variables in the housing bubble environment. The presented measures summarize the occurrences in the housing and financial market which can be classified into three parts: an excessive boom during the expectation phase, a recession, after the housing bubble burst, and a recovery phase when the recession is overcome. The house price level indicated by the mean of all simulation periods amounts 2479.766 without *CCyB* and 2315.595 with *CCyB* and thus is lower than in the base scenario. The excessive price increases during the expectation periods are compensated by the following price drops in the recession. In this environment, the price level of the *CAR* + *CCyB*-regime falls slightly behind this of the *CAR*-regime as price outbreaks are mitigated by the additional capital requirement, and busts are flattened by its relief. The high standard deviation in both the *CAR*- and the *CAR* + *CCyB*-scenario (595.432 and 580.621) indicates the instability of the housing market if market conditions are disturbed by a housing bubble. The coefficients exceed the fluctuations measured in the other shock scenarios. Although the macroeconomic buffer is not able to prevent a crisis caused by a housing bubble, it succeeds in extenuating its extent. The lower standard deviation of housing prices in the *CAR* + *CCyB*-scenario verifies the visualization of Fig. 10. House price oscillations are flattened and cycles are less distinct if the macroprudential tool is installed. When the aftermath of the shock is overcome, prices get very stable and hover slightly around their means.

As the three parts of the housing bubble environment partially offset market mechanisms from previous periods, the mean mortgage interest rate is quite similar to that in the base environment. The increased demand during the expectation phase transmits across the economy in a qualitatively similar manner as in the positive demand shock ("Positive Demand Shock") and banks raise their lending rates. If banks need to hold additional regulatory capital, mortgage

Table 9 Statistical key variables of the housing bubble environments

Housing Bubble		CAR	CAR + CCyB
House Price	Min	1274,847	1469,093
	Max	4480,703	4111,471
	Mean	2479,766	2315,595
	Std	595,432	580,621
Mortgage Interest Rate	Min	0,018	0,016
	Max	0,080	0,096
	Mean	0,037	0,045
	Std	0,069	0,069
Non-Default Probability	Min	0,000	0,000
	Max	0,926	0,940
	Mean	0,555	0,654
	Std	0,364	0,288
Transaction Rate	Min	0,000	0,000
	Max	1,000	1,000
	Mean	0,171	0,153
	Std	0,226	0,227
Homeownership Rate	Min	0,000	0,000
	Max	1,000	0,664
	Mean	0,116	0,111
	Std	0,132	0,137
Construction Rate	Min	0,000	0,000
	Max	4,822	5,934
	Mean	0,091	0,059
	Std	0,137	0,137
Loan Amount	Min	1,00	258,66
	Max	712.302,53	800.509,93
	Mean	188.175,44	184.341,38
	Std	38.081,04	58.919,72
No. of Loans	sum	2093	2001
Z-score	Min	1,808	2,151
	Max	2,914	3,290
	Mean	2,475	2,541
	Std	0,195	0,197

lending is more expensive which transmits to higher lending rates of 0.045 in the $CAR + CCyB$-regime. An offsetting effect sets in as soon as prices decline.

The compensating effects of market phases are also reflected in the non-default probability of borrowers. During the boom phase of the housing bubble environment, the probability of not defaulting is comparable to this of the housing demand shock environment. In the recession, it decreases heavily. When the market recovers, it recovers as well. As a result, the non-default probability in the housing bubble environment is lower than the values of the base scenarios. Similar to the base environment and the other shock environments, the *CCyB* lowers default risk. The probability of not defaulting amounts 0.654 whereas this without an installed *CCyB* reaches 0.555.

The housing bubble environment reaches the second lowest transaction rate (0.171 for the *CAR*-regime and 0.153 for the *CAR* + *CCyB*-regime). The extended recession and the slow recovery of the market limit trading. The same holds true for the construction rates in both regulatory regimes. The pronounced price drops discourage construction firms from building first-time occupancies. As the *CCyB* impacts market activities restrictively, the ratios are depressed in the *CAR* + *CCyB* -regime compared to the *CAR*-regime. The same effect can be seen in the homeownership rate which is lower if banks need to comply with the *CCyB*-regulation.

Considering all simulation periods, the mean values of the loan amount in both the *CAR*-scenario and the *CAR* + *CCyB*-scenario are higher than in the base scenarios which is induced by the excessive boom phase during the first 20 periods. As identified in the other simulation scenarios and in line with the measures so far in the housing bubble environment, the amount of granted loans in the *CAR* + *CCyB* -scenario lies behind the *CAR*-scenario (184,431.38 vs. 188,175.44). The same holds true for the number of accepted mortgages (2001 vs.2093).

The stability of the financial market, indicated by the Z-score can be slightly increased if banks need to comply with the *CCyB* and reaches a value of 2.541. As in the previous environments, the additional capital buffer creates a solid equity base and makes financial institutions less prone to crises. Figure 11 illustrates the distribution of Z-scores within the financial market between the interacting banks. Under both regulatory regimes, some banks feature quite high Z-scores which impact the mean Z-score of the financial market and thus the overall stability positively. As to be seen in Fig. 12, the price appreciations during the expectation phase pushed Z-scores upwards. With ongoing market developments, these appreciations are reversed. Similar to the housing demand shock environment, the development of the Z-scores over time is less stable under the *CAR*-regime than under the *CAR* + *CCyB*-regime.

The stabilizing effects of the *CCyB* are verified in Table 10. The length of housing market cycles is lowered to 20.3, the number of cycles increases (3.4), and the number of cycle outbreaks that exceed the standard deviation decreases to 32.0 compared to 51.0. Thus, the simulations show that in the event of a housing bubble, the *CCyB* is not a prevention but a helpful tool to reduce spillover effects to adjacent markets and to stabilize the economy. Although house price appreciations are dampened during the boom phase, it goes on for too long even if the macroprudential feature is installed. The recession that follows the burst cannot be avoided, its extent can only slightly be mitigated. Overall, however, the *CCyB* helps to attenuate the impacts of a housing bubble on the housing and the financial markets.

Conclusions

As the rules of Basel II were not able to prevent the latest financial crisis nor to mitigate spillover effects to the overall economy, the authority introduced a set of micro- and macroprudential measures that aim at strengthening the financial sector and dampening the economic impact. The *CCyB* is one of the post-crisis reforms of Basel III that

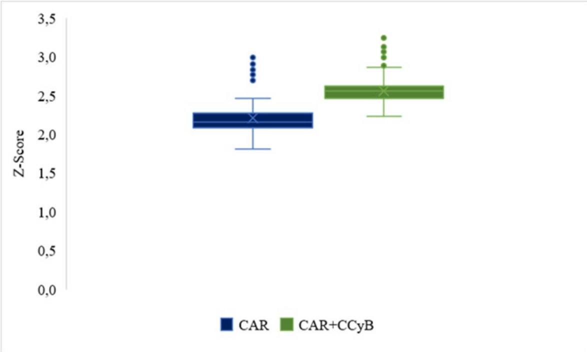

Fig. 11 Z-scores of the housing bubble environment

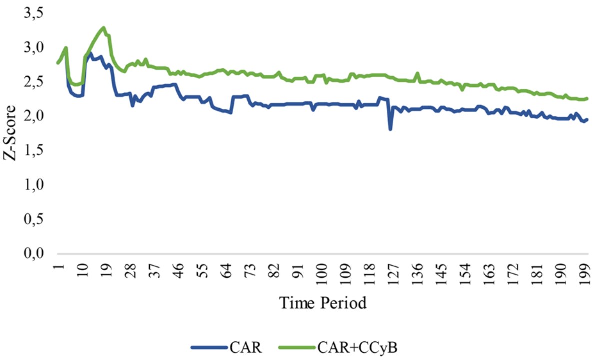

Fig. 12 Development of Z-scores in the housing bubble environment

Table 10 Market cycle properties of the housing bubble environment

Housing Bubble	CAR	CAR + CCyB
Average Cycle Length	26.7	20.3
No. of Cycles	7.5	9.9
No. of Outbreaks	51.0	32.0

Table 10 displays some properties of the housing market cycles occurring in the two regulatory regimes. For details see Table 4

allows national authorities to adjust *CAR* in a countercyclical manner. To limit credit-based economic upturns, banks shall build additional equity capital in times of excessive credit growth that tightens their scope for economic activity. In recessionary times, in contrast, the built buffer shall be released to assist a sufficient supply of capital.

This paper investigates the effects of the new regulatory tool on the housing and the financial market and assesses its effectiveness in preventing excessive credit growth, increasing the resilience of the financial sector, and avoiding any destabilization of the economy. Due to the capital-intensive and collateral value-based lending practices in housing investment, the mortgage lending market acts as a direct transmission channel of occurrences in one of both markets to the next that fuels the financial accelerator. The resulting close interconnectedness of the two markets and the enormous impact of the turmoil in one of them on the overall economy raises particular interest in whether the *CCyB* succeeds in achieving regulatory goals.

For this purpose, we extend the heterogeneous agent-based model (ABM) of Braun et al. (2022) and investigate key stability indicators of the housing and the financial market under undisturbed market conditions and in times of three different shocks. The model builds a network of potential home buyers, sellers, and financial institutions that build a decentralized credit market where heterogeneous borrowers and banks interact directly with each other. The model features two binding constraints: while potential buyers are constrained in borrowing, banks are constrained in conducting business according to the *CAR* including a *CCyB* which is positively linked to credit growth.

The resilience of the housing and the financial market can be affected from both the inside of the market and its inherent structures and from the outside through exogenous shocks. Hence, to quantitatively evaluate the impact of the new macroprudential tool of Basel III, a model has to be used that incorporates these various sources of risk while at the same time considering the heterogeneity of economic agents. An ABM accounts for these characteristics and develops an artificial market environment that allows us to investigate endogenously created market conditions as well as to test the *CCyB′s* performance during times of exceptional market occurrences induced by external shocks.

In the context of this model, we conduct several computational experiments and examine four simulation scenarios: one in which market conditions evolve endogenously in the absence of any exogenous shocks which serves as a benchmark, and three shock scenarios where the markets face a financial shock, a positive housing demand shock, or a housing bubble. We find that in every scenario, the *CCyB* performs well in stabilizing the housing market. House price fluctuations are dampened if the national authority forces banks to build an additional capital buffer in times of excessive increase in credit. The higher *CAR* increase the cost of mortgage lending. This induces banks to rise mortgage interest rates which, in turn, has a restraining effect on credit demand. The dissolution of the *CCyB* in recessionary times softens banks previously tightened business activities, thus cushioning sharp price downturns. These mechanisms positively affect the non-default probability of borrowers and the resilience of the financial sector. The higher equity capital under the $CAR + CCyB$-regimes, the higher returns of mortgage lending as well as the lower riskiness of borrowers lead to increased banking soundness indicated by a higher Z-score. These positive effects coincide, however, with limited business activities in the housing market. The tightening effect of increased capital requirements distorts supply and demand in the housing market transmitted through the mortgage lending channel. The results are lower transaction and construction rates and also a lower rate of homeownership in the base scenario, the financial shock scenario, and the housing bubble scenario. These effects might negatively impact overall prosperity, health, or social concerns.

Although the *CCyB* performs well in stabilizing the housing and the financial market, the decision about mortgage lending of banks is still mainly based on collateral values and LTVs of borrowers. The *CCyB* may moderate the effects of these lending practices but as they are inherently procyclical, sharp price outbreaks, induced by excessive generous or limited credit cannot be banned. This is revealed by the different shock scenarios. The development of house prices discloses that neither the financial shock, the housing demand shock nor the housing bubble can be prevented by the *CCyB*. Price trends are distorted by the external shocks that hit the markets quite similarly under both regulatory regimes. However, due to the restraining effect on procyclicality, the *CCyB* helps to end a housing bubble earlier. On top, in the aftermath of the respective crisis, housing market cycles are significantly mitigated if banks need to comply with the macroprudential tool of Basel III. As such, the effectiveness of the *CCyB* in mitigating downfalls and cushioning shocks can be judged positively.

Furthermore, the design of the *CCyB* reduces the mutual dependencies of banking regulations and monetary policy. Introducing a measure that depends on ongoing market conditions counteracts the procyclicality of previous regulatory measures. The spillover effects of interest rate changes due to monetary policy may be cushioned by the *CCyB* that prevents a sharp interest rate impact that is induced by political considerations rather than economic features.

Compared to the other shock scenarios, the housing bubble destabilizes the housing market the most. The standard deviation of house prices exceeds those of the other scenarios and the *CCyB* has the highest stabilizing effect. The positive housing demand shock affects fluctuations the least. The highest banking soundness can be achieved in the financial shock scenario. This is due to the low standard deviation of high mortgage interest rates. The largest increase in banking stability in the $CAR + CCyB$-regimes can be recorded in the positive demand shock scenario. If prices rise excessively because of a huge increase in housing demand, which is further induced by procyclical mortgage lending practices, the limiting effect of the *CCyB* forces banks to build a solid base of additional capital.

The shock scenarios further indicate that the effectiveness of the *CCyB* depends on the magnitude of the shock and on how much buffer has been built up by banks in the previous periods. Accordingly, the time at which the buffer is introduced by the national authority is decisive for its effectiveness. Since banks follow their usual decision processes of mortgage lending, a *CCyB* introduced at the wrong time might even affect market conditions procyclically, further fueling the financial accelerator mechanism.

This paper's findings provide insights for regulatory authorities about the effectiveness of the *CCyB* in the context of the housing and mortgage lending market. It identifies the macroprudential tool of Basel III as a useful measure to stabilize the housing and the financial market in uneventful market conditions as well as in mitigating the aftermaths of different shocks. It is not able, however, to prevent any of the simulated crises to occur. The insights also contribute to a better understanding of how higher *CAR* impact the pricing and the availability of mortgage loans. Furthermore, the results highlight the decisiveness of the timing of the introduction of the *CCyB* for its performance. As the simulations reveal, the *CCyB* affects the housing market and the financial market noticeably. Thus, it may be assumed that an installation at the wrong time may have contradictive results. Discussions in the existing literature about regulatory measures that indicate the timing of installation have not come to an end yet. This leaves room for further research.

Appendix

The results presented in the main part of this paper constitute one exemplary simulation run each. To ensure that the findings are representative, we test the model's robustness and its structural consistency by running extensive Monte Carlo simulation experiments. We compute 200 independent simulation runs of the base and the shock scenarios that cover 200 periods each. Table 13 to Table 20 show the mean values of the examined key variables and their standard deviations for the different market settings under the two regulatory regimes: the *CAR*-only-regime and the *CAR* + *CCyB*-regime. The results of the Monte Carlo simulations validate the findings presented in "Base Scenario" to "Housing Bubble" and affirm their robustness. Table 11 presents the requested risk weights depending on borrowers' LTV levels according to the BCBS (BCBS, 2017b). Table 12 summarizes the variations of model parameters in the different shock scenarios.

Tables 11, 12, 13, 14, 15, 16, 17, 18, 19 and 20

Table 11 Risk weight table for residential real estate exposure

	LTV ≤ 50%	60% < LTV ≤ 80%	80% < LTV ≤ 90%	90% < LTV ≤ 100%	LTV > 100%
Risk weight	20%	25%	30%	40%	70%

Table 12 Variation of simulation parameters in the shock scenarios

Scenario	Shock Type	Period	Parameter	Value
Financial Shock	exogenous, unanticipated	0–10	r_t	0.02
		11–200	r_t	$r_t + 0.05$
Positive Demand Shock	exogenous, unanticipated	0–10	α	$[0, 1], \mu = 0.5, \sigma = 0.05$
		11–200	α	$[0, 1], \mu = 0.2, \sigma = 0.02$
Housing Bubble	endogenous, anticipated	0–20	α	$[0, 1], \mu = 0.2, \sigma = 0.01$
		21–200	α	$[0, 1], \mu = 0.6, \sigma = 0.05$

Table 13 Robustness check of the statistical key variables of the base environment

Base Scenario		CAR	CAR + CCyB
House Price	Min	1710.076	1741.402
		(256.334)	(263.262)
	Max	3432.949	3308.123
		(204.975)	(227.975)
	Mean	2439.658	2601.283
		(400.635)	(303.490)
Mortgage Interest Rate	Min	0.010	0.009
		(0.006)	(0.007)
	Max	0.069	0.060
		(0.011)	(0.013)
	Mean	0.038	0.039
		(0.009)	(0.009)
Non-Default Probability	Min	0.000	0.000
		(0.000)	(0.000)
	Max	0.889	0.905
		(0.035)	(0.029)
	Mean	0.653	0.774
		(0.055)	(0.052)
Transaction Rate	Min	0.000	0.000
		(0.000)	(0.000)
	Max	0.984	0.981
		(0.078)	(0.093)
	Mean	0.179	0.176
		(0.032)	(0.036)
Homeownership Rate	Min	0.000	0.000
		(0.000)	(0.000)
	Max	0.515	0.501
		(0.219)	(0.213)
	Mean	0.122	0.102
		(0.021)	(0.024)
Construction Rate	Min	0.000	0.000
		(0.000)	(0.000)
	Max	2.431	2.967
		(4.345)	(5.006)
	Mean	0.188	0.115
		(0.061)	(0.065)
Loan Amount	Min	113.79	56.56
		(556.00)	(393.44)
	Max	998,608.26	924,415.51
		(175,308.08)	(179,606.43)
	Mean	184,859.06	145,901.08
		(38,767.48)	(43,360.82)

Table 13 (continued)

Base Scenario		CAR	CAR + CCyB
No. of Loans	sum	1936	1871
		(369.127)	(431.596)
Z-score	Min	2.194	2.349
		(0.451)	(0.432)
	Max	3.084	3.211
		(0.413)	(0.307)
	Mean	2.695	2.911
		(0.270)	(0.141)

Table 14 Robustness check of the market cycle properties of the base environment

Base Scenario	CAR	CAR + CCyB
Average Cycle Length	10.3	9.9
No. of Cycles	22.1	21.0
No. of Outbreaks	46.1	35.8

Table 15 Robustness check of the statistical key variables of the financial shock environment

Financial Shock		CAR	CAR + CCyB
House Price	Min	897.440	1040.164
		(663.614)	(626.711)
	Max	3353.861	3068.614
		(135.731)	(120.712)
	Mean	1964.969	1897.596
		(566.265)	(428.027)
Mortgage Interest Rate	Min	0.067	0.069
		(0.012)	(0.012)
	Max	0.114	0.127
		(0.022)	(0.018)
	Mean	0.089	0.096
		(0.012)	(0.014)
Non-Default Probability	Min	0.000	0.000
		(0.000)	(0.000)
	Max	0.586	0.613
		(0.205)	(0.193)
	Mean	0.286	0.313
		(0.169)	(0.124)
Transaction Rate	Min	0.000	0.000
		(0.000)	(0.000)
	Max	0.906	0.971
		(0.310)	(0.320)
	Mean	0.179	0.088
		(0.094)	(0.081)
Homeownership Rate	Min	0.000	0.000
		(0.000)	(0.000)
	Max	0.724	0.687
		(0.299)	(0.306)
	Mean	0.120	0.073
		(0.072)	(0.056)
Construction Rate	Min	0.000	0.000
		(0.000)	(0.000)
	Max	2.640	1.396
		(5.003)	(2.672)
	Mean	0.074	0.062
		(0.070)	(0.045)
Loan Amount	Min	152.20	1.00
		(723.05)	(0.00)
	Max	362,36.77	360,065.61
		(257,381.14)	(197,599.36)
	Mean	105,296.83	86,915.41
		(48,153.20)	(57,778.42)

Table 15 (continued)

Financial Shock		CAR	CAR + CCyB
No. of Loans	sum	1236	976
		(93.248)	(97.285)
Z-score	Min	2.556	2.661
		(0.144)	(0.159)
	Max	3.091	3.111
		(0.344)	(0.367)
	Mean	2.991	3.226
		(0.354)	(0.377)

Table 16 Robustness check of the market cycle properties of the financial shock environment

Financial Shock	CAR	CAR + CCyB
Average Cycle Length	19.6	10.6
No. of Cycles	10.2	18.9
No. of Outbreaks	78.3	61.2

Table 17 Robustness check of the statistical key variables of the demand shock environment

Demand Shock		CAR	CAR + CCyB
House Price	Min	2094.941	2324.956
		(262.463)	(265.545)
	Max	4266.697	4387.206
		(148.606)	(155.222)
	Mean	3389.443	3420.846
		(418.743)	(304.527)
Mortgage Interest Rate	Min	0.010	0.014
		(0.007)	(0.007)
	Max	0.085	0.095
		(0.018)	(0.013)
	Mean	0.045	0.049
		(0.008)	(0.006)
Non-Default Probability	Min	0.000	0.000
		(0.000)	(0.000)
	Max	0.886	0.800
		(0.085)	(0.093)
	Mean	0.572	0.643
		(0.121)	(0.076)
Transaction Rate	Min	0.000	0.000
		(0.000)	(0.000)
	Max	0.975	0.989
		(0.051)	(0.032)
	Mean	0.181	0.177
		(0.008)	(0.008)
Homeownership Rate	Min	0.000	0.000
		(0.000)	(0.000)
	Max	0.366	0.541
		(0.111)	(0.183)
	Mean	0.064	0.079
		(0.005)	(0.009)
Construction Rate	Min	0.000	0.000
		(0.000)	(0.000)
	Max	3.062	4.302
		(6.209)	(6.936)
	Mean	0.133	0.123
		(0.082)	(0.082)
Loan Amount	Min	6,026.73	1,034.20
		(5,917.51)	(2,403.09)
	Max	1,364,444.39	1,106,265.53
		(142,080.13)	(146,269.66)
	Mean	541,263.43	385,793.71
		(45,557.88)	(37,543.47)

Table 17 (continued)

Demand Shock		CAR	CAR + CCyB
No. of Loans	sum	1912	1833
		(91.565)	(115.878)
Z-score	Min	1.523	2.063
		(0.697)	(0.369)
	Max	2.981	3.026
		(0.318)	(0.404)
	Mean	2.453	2.967
		(0.500)	(0.307)

Table 18 Robustness check of the market cycle properties of the demand shock environment

Demand Shock	CAR	CAR + CCyB
Average Cycle Length	11.6	7.5
No. of Cycles	17.2	26.6
No. of Outbreaks	42.4	31.9

Table 19 Robustness check of the statistical key variables of the housing bubble environment

Housing Bubble		CAR	CAR + CCyB
House Price	Min	14,342.038	1471.342
		(262.463)	(373.380)
	Max	4504.159	4237.246
		(154.679)	(173.357)
	Mean	2648.447	2575.308
		(838.560)	(695.003)
Mortgage Interest Rate	Min	0.011	0.014
		(0.006)	(0.007)
	Max	0.079	0.089
		(0.013)	(0.015)
	Mean	0.039	0.046
		(0.008)	(0.013)
Non-Default Probability	Min	0.000	0.000
		(0.000)	(0.000)
	Max	0.952	0.929
		(0.235)	(0.229)
	Mean	0.574	0.690
		(0.164)	(0.145)
Transaction Rate	Min	0.000	0.000
		(0.000)	(0.000)
	Max	0.980	0.984
		(0.065)	(0.060)
	Mean	0.168	0.161
		(0.034)	(0.043)
Homeownership Rate	Min	0.000	0.000
		(0.000)	(0.000)
	Max	0.657	0.669
		(0.200)	(0.216)
	Mean	0.107	0.100
		(0.025)	(0.029)
Construction Rate	Min	0.000	0.000
		(0.000)	(0.000)
	Max	4.021	4.684
		(3.672)	(5.017)
	Mean	0.092	0.051
		(0.050)	(0.068)
Loan Amount	Min	461.49	118.91
		(5,917.51)	(773.89)
	Max	965,067.41	953,710.12
		(196,793.12)	(225,890.96)
	Mean	187,063.74	179,267.94
		(38,665.07)	(48,652.91)

Table 19 (continued)

Housing Bubble		CAR	CAR + CCyB
No. of Loans	sum	1869	1822
		(398.930)	(515.468)
Z-score	Min	1.902	2.129
		(0.330)	(0.355)
	Max	3.035	3.247
		(0.246)	(0.260)
	Mean	2.448	2.571
		(0.286)	(0.322)

Table 20 Robustness check of the market cycle properties of the housing bubble environment

Housing Bubble	CAR	CAR + CCyB
Average Cycle Length	29.0	20.0
No. of Cycles	6.9	10.0
No. of Outbreaks	57.7	34.8

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